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MEMORANDUM REPORT NO. 2031

AN EMPIRICALLY BASED ANALYSIS ON THE RESPONSE OF HE MUNITIONS TO IMPACT BY STEEL FRAGMENTS (U)

by

Harry J. Reeves

March 1970

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BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 2031

MARCH 1970

AN EMPIRICALLY BASED ANALYSIS ON THE RESPONSE OF HE MUNITIONS TO IMPACT BY STEEL FRAGMENTS (U)

Harry J. Reeves

Vulnerability Laboratory

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MEMORANDUM REPORT NO. 2031

HJReeves/bjr
Aberdeen Proving Ground, Md.
March 1970

AN EMPIRICALLY BASED ANALYSIS ON THE RESPONSE OF HE MUNITIONS TO IMPACT BY STEEL FRAGMENTS (U)

(UNCLASSIFIED) ABSTRACT

Efforts to derive a satisfactory measure of the vulnerability of High Explosive munitions to steel fragment impact have been hampered by a lack of experimental data. In an attempt to remedy this deficiency, a number of tests have been carried out.

This report presents the results of tests of firings of steel fragments against U.S. 90mm, 105mm, and 175mm HE (Comp. B) artillery projectiles, Soviet 57mm HE (RDX/Aluminum/wax) artillery projectiles, Soviet 122mm and 152mm HE (TNT) artillery projectiles, Soviet 140mm HE (TNT) rocket projectiles, U.S. 81mm and Soviet/CHICOM 82mm mortars (TNT), and a variety of U.S. Sub-Missile munitions.

These firing data were used to determine contributions of fragment striking mass and velocity required to initiate explosive reactions.

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I. INTRODUCTION

The Ballistic Research Laboratories are presently engaged in an analysis of the vulnerability of a wide variety of air and ground targets to fragment impact. To complete vulnerability studies on weapon systems such as field artillery, tank, aircraft and anti-aircraft systems, the vulnerability of the High Explosive (HE) munitions belonging to each system has to be determined.

A review of available data dealing with the vulner f explosives and explosive-filled munitions revealed that, with the exception of bomb vulnerability, only limited, empirically-based, vulnerability data have been generated for most types of HE munitions. The data that are available result from limited ad hoc testing. It is not possible to interpolate among and/or extrapolate from the results of these tests because of the wide variations in the testing and target parameters. A summary of the results of these investigations is discussed in parts A and B of Section II of this report.

This report presents vulnerability data on a wide variety of HE projectiles to steel fragment impact. Included are the results of extensive testing against Composition B (Comp. B)-loaded U.S. artillery projectiles and several types of Sub-Missile munitions and the results of limited testing against foreign artillery, rocket and mortar projectiles. The data from the limited testing against foreign munitions do not provide a sound basis for rigorous statistical analysis but are sufficient for a comparative analysis of the effects of steel fragment impacts versus U.S. and foreign munitions.

Threshold fragment mass-velocity combinations required for an explosive reaction with an associated probability of 0.5 have been established by fitting least squares polynomials to the data from the firing records for the U.S. artillery projectiles and Sub-Missile munitions. These data were used to generate cumulative-probability curves for the artillery projectiles. Assumptions upon which the cumulative probability curves are based are specified in the text.

The vulnerability of the foreign munitions and the U.S. mortar projectiles were determined by plotting the median values for explosive reactions from their respective firing tables. In all cases, interpolations and extrapolations were required because of the limited number of data points.

(CONFIDENTIAL) II. DISCUSSION

This section has been included to familiarize the reader with some of the data that are available on the vulnerability of explosives and with the way in which these data relate to the vulnerability of HE munitions.

A. Bare Charge Attack

Slade and Dewey[1*], in the abstract of their report, state that: "Firings of right cylinders against bare tetryl and Composition B show that the velocity for 50 percent initiation is a function of contact area but not of mass nor of the form of the projectiles behind the contacting surface." Brown, Steel and Whitbread[2], using different types of explosive targets, recorded results confirming these findings. Because extensive sensitivity data on Comp B. were already available, this explosive was selected as a filler for tests conducted against the U.S. artillery projectiles. Unfortunately, similar data are not available on other common HE fillers.

B. Covered Charge Attack

Most investigators [1, 2, 3, 4, 5] have recorded data indicating that, for a given fragment, the striking velocity required to achieve a 50 percent probability of detonating a covered HE charge is directly proportional to the thickness of the cover plate. These results were observed when both the HE type and cover plate composition were varied and the attack angle was kept constant.

References are listed on page 61.

C. Explosive Reactions

No attempt was made during the tests discussed in this report to determine the mechanism responsible for the explosive reactions which occurred. In the consideration of fragment impacts on HE projectiles, one or more of the following mechanisms may affect the outcome.

1. Initiation by Single Shock. A compression wave is formed which reinforces the original shock wave and forms a detonation wave.

2. Initiation by Multiply-Reflected Shocks. A reflected shock wave from a boundary meets the oncoming projectile head-on.

3. Surface Initiation. The temperature of the surface layer of the explosive rises very quickly.

4. Initiation Caused by Hot Objects Embedded in the Explosive. Impacting fragments are heated as they perforate the projectile wall before they come to rest within the HE filler. The shape of the impacting fragment is critical if this is the mechanism involved.

Any attempt to determine which of these mechanisms causes or cause the explosive reaction requires the measurement of "induction times". The induction time is defined as he time between the moment an explosive is attacked and the moment reaction is initiated. Unfortunately, the techniques and instrumentation required to obtain such measurements are not conducive to large-scale, explosive, field testing. Such measurements are normally obtained in a laboratory using small charges.

D. Application

Attempts to extrapolate from basic explosive vulnerability data have been hampered by the sparseness of the basic data available. The number of impact parameters involved in an analysis of the vulnerability of explosives can be quite large, and the interactions between and among these parameters have not been quantitatively established or even considered in many cases.

Fragment attack against HE-filled projectiles can cause the projectiles to function explosively. The explosive reactions of these HE projectiles

to fragment attack can be conveniently grouped into two categories: shock-initiated reactions and non-shock initiated reactions. This technique allows us to discuss in a qualitative manner those fragment and projectile characteristics that determine the probability of a successful attack.

1. Shock-Initiated Reactions. When a fragment strikes the wall of an HE-filled projectile a shock wave is transmitted to the filler. The ability of this shock wave to trigger an explosive reaction is dependent on the following:

a. Fragment Characteristics. Striking velocity, weight, fragment geometry (contact area), shock impedance*, and obliquity angle.

b. Projectile Characteristics. Wall thickness at the point of impact, shock impedance of the casing, protective coatings (paint or enamel applied to the interior surface of the projectile could provide protection via an impedance mismatch), HE filler sensitivity to shock initiation and HE filler shock impedance.

Shock-initiated reactions are characterized by the following:

a. The probability that a given HE projectile will react explosively to fragment impact will increase as the impact velocity, striking weight or the area of the fragment impinging on the target increases. The probability of reaction will also increase as the ratio of shock impedance of the fragment to that of the projectile approaches unity.

b. The probability that a given fragment striking any HE projectile will initiate an explosive reaction will increase as the HE sensitivity increases and as the projectile wall thickness decreases.[6]

The shock impedance of a material is defined as the product of its density and velocity with which a shock wave propagates in it. The efficiency with which shock is transmitted from one material to another is a function of the impedance match of the two materials. The most efficient coupling will be realized when the impedances of the two materials are equal.

The impedance matches between the fragment and projectile wall, projectile wall and any coating material and the interior surface of the projectile, and between any coating material and the HE filler will also affect the probability of initiation. The more efficient the coupling of the shock wave from the fragment to the projectile wall to any coating material to the HE filler, the greater will be the probability of an explosive reaction.

2. Non-Shock Initiated Reactions. Fragments often perforate the casing of HE projectiles without triggering any explosive or burning reactions. However, a perforation criterion appears to be an effective means of predicting an explosive or burning reaction. If a fragment must first perforate the casing of a projectile before any explosive or burning reactions are observed, and shock is not the mechanism of initiation, then embedded hot fragments within the HE filler appear to be likely candidates for initiating an explosive or burning reaction.

While a fragment perforates the casing of an HE projectile, the fragment experiences a temperature rise. The magnitude of the rise is a function of both fragment and casing characterisitics, and is directly proportional to the thickness of the casing material.

The probability that a hot fragment embedded in the HE filler will initiate an explosive reaction is determined by the temperature of the fragment and the sensitivity of the HE filler to heat. The fact that a fragment perforates the casing of an HE projectile before any explosive reaction is observed, does not necessarily imply that the hot fragment is the initiating mechanism. It may well be that the shock from the striking fragment would have been sufficient in itself to initiate the reaction.

The foregoing discussion is provided to point up some of the difficulties one has in trying to predict exactly what caused a particular reaction in the explosive in terms of meaningful parameters. The British Ordnance Board report by Ledsham[6] treats this problem in considerable detail.

(UNCL) III. SCOPE OF STUDY AND TEST PROCEDURES

This report presents data on the vulnerability of a wide variety of HE munitions to steel fragment and bullet impact. Firings were carried out against U.S. 90mm, 105mm, 155mm, and 175mm HE (Comp. B) artillery projectiles, Soviet 57mm HE (RDX/aluminum/wax) artillery projectiles, Soviet 122mm and 152mm HE (TNT) artillery projectiles, Soviet 140mm HE (TNT) rocket projectiles, U.S. 81mm and Soviet/CHICOM 82mm mortar projectiles (TNT), and five types of U.S. Sub-Missile munitions.

Over 800 firings were conducted in this program. A breakdown of these firings by fragment and munition type is presented in Table I. A physical description of the artillery, rocket and mortar projectiles can be found in Appendix E. A physical description of the Sub-Missile munitions is available from the Warhead and Special Projects Laboratory at Picatinny Arsenal.

A. Approach

U.S. projectiles were selected for large-scale testing because of their availability in suitab quantities. The 105mm, in particular, was subjected to extensive testing because it has a thinner wall than the other U.S. projectiles identified above. It was anticipated before testing, that because of fragment striking velocity requirements, vulnerability data could be more easily generated against the thinner-walled projectiles.

Because the sensitivity of bare Comp. B to steel fragment impact had already been established, it was selected as a filler for the U.S. artillery projectiles.

Prior to explosive testing, steel fragments were fired against empty U.S. projectiles to establish the fragment mass-velocity combinations required for perforation. The impact location was defined as a circular area, one inch in diameter, centered over the aim point, see Figure 1. Impacts registered outside this area that did not result in explosive

TABLE I. SUMMARY TABLE
Total Number of Firings
Steel Fragments Versus HE Munitions

Target Type	Fragment Weight (Grains)					
	30-HD*	30	60	120	240	480
U.S. Artillery Projectiles						
90mm			29	18	27	
105mm		52	34	56	46	
155mm			4	31	28	
175mm			4	40	35	
Soviet Artillery Projectiles						
57mm			1	4	5	
122mm			10	5	7	
140mm					9	6
152mm			1	6	2	
U.S. 81mm and Soviet/CHICOM 82mm Mortars						
81mm			1	12	4	
82mm			1	1	3	
U.S. Sub-Missile Munitions						
M-32	51					
M-40	33		20	31	36	
M-43E1		7	6	9	9	
XM-41	13		4	5	4	
XM-42	25		32	27	17	

*30 HD = 30 Grain High Density Steel (Mallory 3000). Remaining fragments were case-hardened to Rockwell C-30.

reactions were assessed as poor hits. The rational behind these preliminary tests was twofold: (1) the tests could be conducted inexpensively at an indoor test facility with experimental errors kept to a minimum, and (2) the data obtained would provide the Test Director, who conducts the explosive testing in the field, with a priority of the impact conditions to be considered.

During the explosive-testing phase, fragments were again fired to impact close to and above the bourrelet. However, in this phase, effects of fragment impacts at angles of both zero and forty-five degrees were considered (see Figure 1). Observations made during this test phase indicate that for a given fragment mass, the impact velocity required for perforation of the wall an HE filled projectile is greater than that required to perforate the wall of an empty projectile. The magnitude of this velocity increase was determined by conducting fragment impact tests against projectiles containing wax of the same density as Comp. B.

The data obtained on the vulnerability of the foreign artillery, mortar and rocket projectiles and the U.S. mortar rounds are the result of several ad hoc tests. The results of these tests have been included only for comparative purposes, since they were based on small samples of data.

Extensive firings were conducted against five different types of Sub-Missile munitions. Target configurations were varied to include firings against bare rounds and rounds shielded by thin aluminum plate. In some cases, the target configurations simulated to a high degree a missile warhead employing these rounds as a payload. In addition to the mild steel fragments, 30 grain High Density (HD) fragments were fired against these rounds to satisfy an additional requirement.

B. Test Procedures

In all the fragment impact phases of the tests, compact, cylindrically shaped, steel fragments weighing 30, 60, 120, 240 and 480 grains were used (see Figure 2).

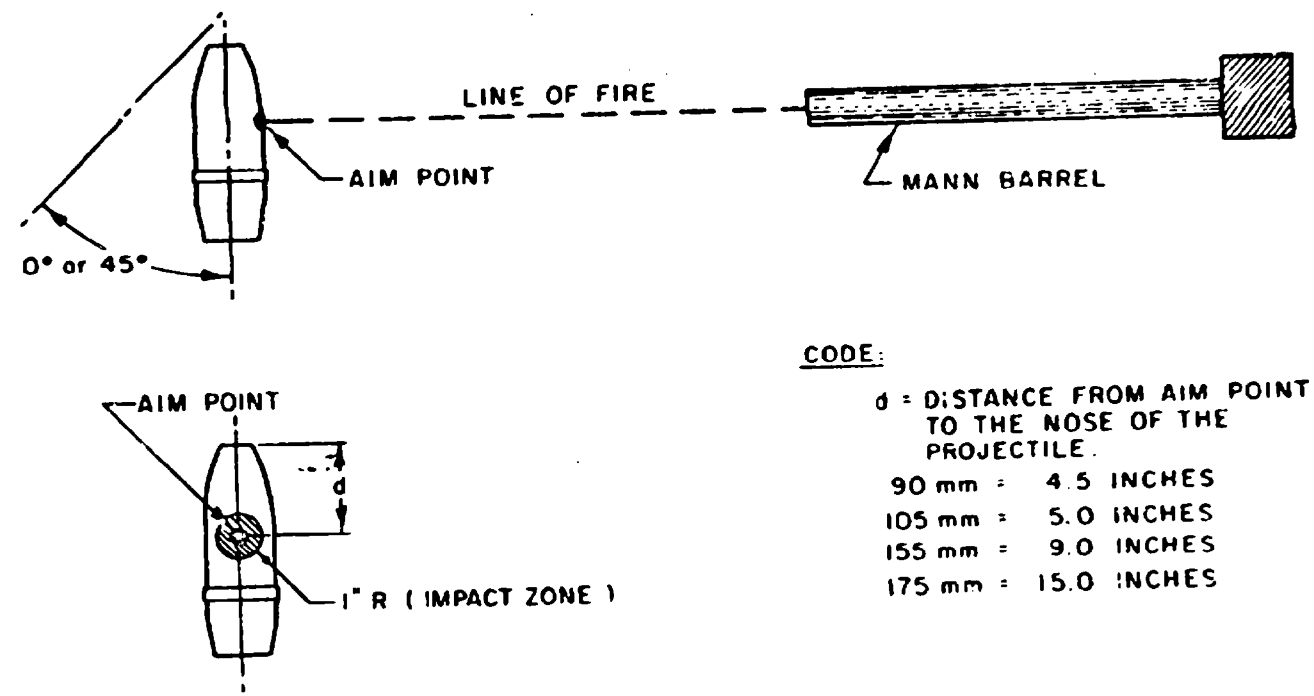
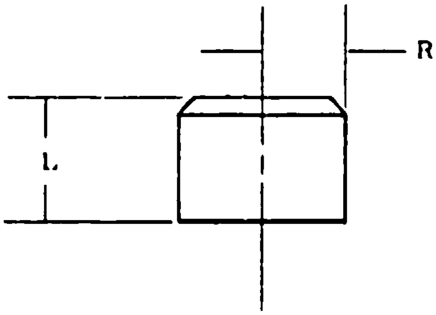


Figure 1. Projectile Orientation



WEIGHT (GRAINS)	RADIUS R (INCHES)	LENGTH L (INCHES)	AVERAGE PRESENTED AREA (SQ. INCHES)
30HD	0.117	0.163	0.0500
30	0.15	0.225	0.0884
60	0.20	0.248	0.1533
120	0.249	0.315	0.2210
240	0.2985	0.451	0.3511
480	0.3435	0.660	0.5425

NOTE: 30 HD = 30 Grain High Density Steel (Mallory 3000). Remaining fragments were case-hardened to Rockwell C-30.

Figure 2. Characteristics of Steel Fragments

Smoothbore Mann barrels mounted on a "Frankford Mount" were used for propelling fragments at velocities up to approximately 2050 meters per second. For higher velocities a light gas gun was used. A chronograph and "break screens" provided the means for obtaining velocity measurements.

An overall schematic of the field test set-up and firing chamber is shown in Figures 3 and 4. The muzzle-to-target distance illustrated was used for firing against the smaller caliber projectiles. It was necessary to increase the muzzle-to-target distance when firing against the larger caliber projectiles to protect the firing chamber.

(CONFIDENTIAL) IV. RESULTS AND OBSERVATIONS

The results of over 800 individual firings have been grouped into four categories: (1) U.S. artillery projectiles, (2) Soviet artillery and rocket projectiles, (3) U.S. and Soviet/CHICOM mortar projectiles, and (4) U.S. Sub-Missile munitions. The results are presented in tabular form in Appendices A through D of this report.

Considerable data were generated on U.S. artillery and Sub-Missile munitions. Consequently, those firings against the U.S. artillery and Sub-Missile munitions which resulted in poor hits were deliberately omitted from Appendices A and D. Those test results associated with poor hits were considered outside the range of interest of this study. Because data generated on the remaining munitions were limited, all available results, including some which may have very limited value, for these munitions, were included in Appendices B and C.

Observations based on these firing records are discussed below. In the discussion, tables identified by a letter hyphenated to a Roman numeral will be found in the appendix associated with the letter.

A. U. S. Artillery Projectiles

Tables A-I through A-IV present the results of firings conducted with empty and wax-filled artillery projectiles. In general, as would

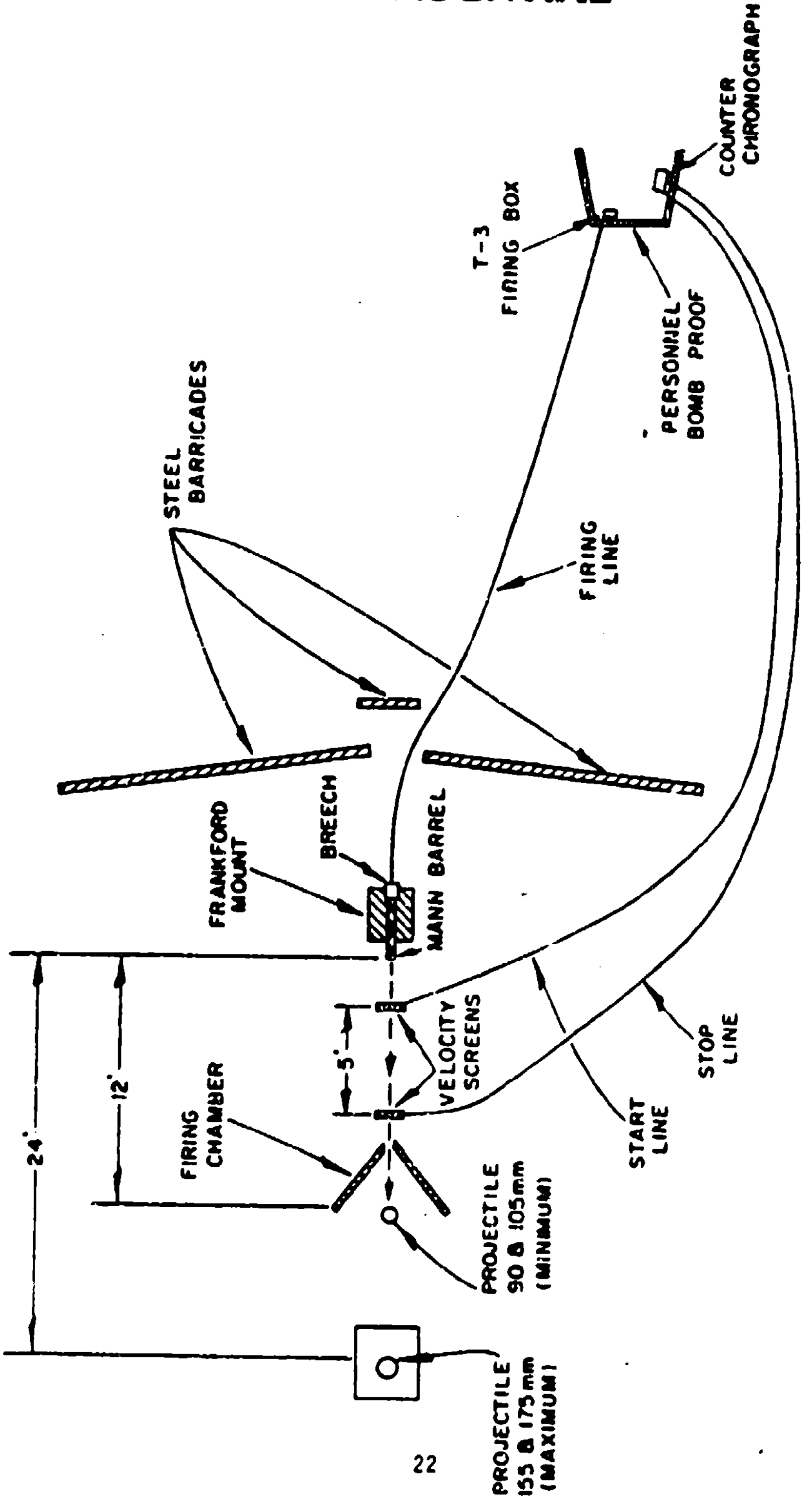


Figure 3. (U) Test Setup

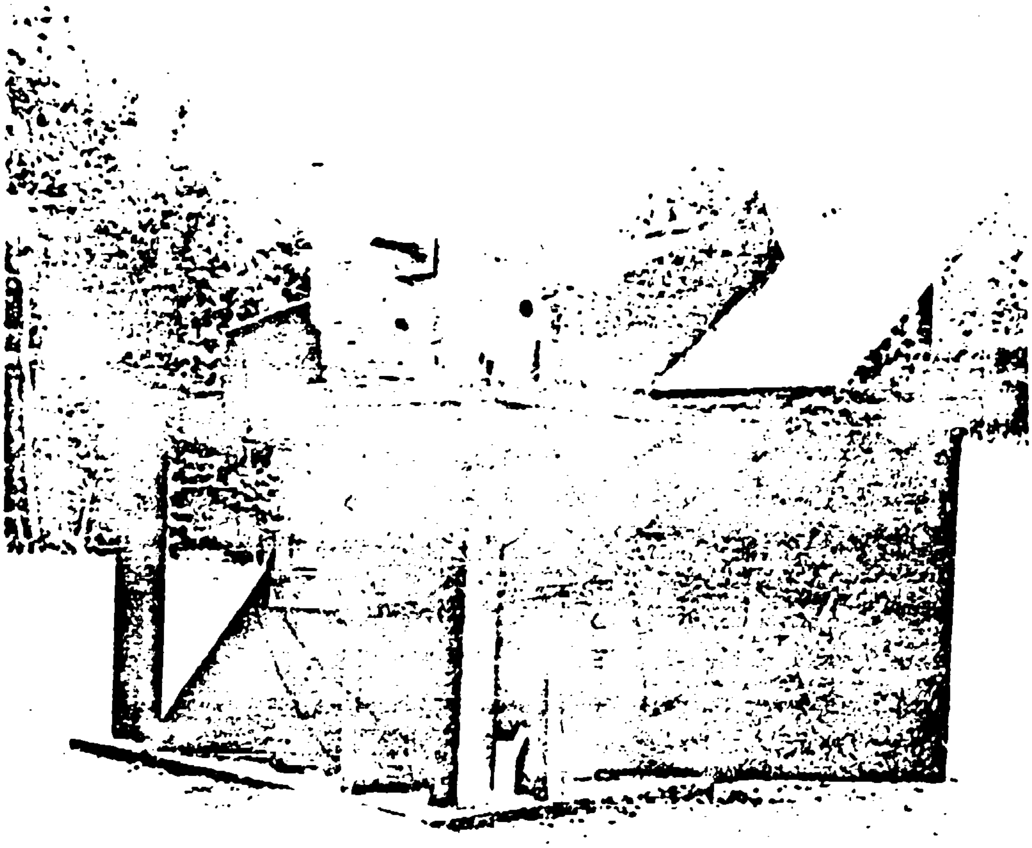


Figure 4. (U) Firing Chamber

be expected, it is observed that the impact velocity required by a given fragment to perforate the wall of an empty projectile increases as the wall thickness of the projectile increases. These Laboratories believe that observed departures from this general trend are due to small variations in the average wall thickness of the four types of projectiles tested and to variations in the wall thickness of individual projectiles.

Table A-II presents the results of tests conducted against wax-filled projectiles. Test results suggest that if some given fragment requires some minimum impact velocity to perforate the wall of an empty projectile, then an increase of approximately 100 meters per second in the impact velocity is needed for the fragment to perforate the wall of the same projectile when it is filled with wax.

The results of the firings conducted against U.S. Comp. B-loaded 90, 105, 155 and 175mm projectiles are presented in Tables A-V through A-IX. It is observed that:

1. For a given fragment, the impact velocity required to initiate an explosive or burning reaction increases as projectile wall thickness increases. However, it is noted that the 155mm projectiles used in this test were originally issued with a TNT filler. The TNT was "steamed" out and replaced with Comp. B at the Aberdeen Proving Ground. During the steaming-out process, the asphalt-based paint coating on the interior of the projectile was washed out. This changes the impedance match between the projectile and the filler and could have influenced the sensitivity of the round to shock initiation.

2. High Order, Low Order, and Burning Reactions resulted from similar impact mass and velocity combinations. The minimum impact velocities, for a given mass producing these reactions, were essentially the same.

3. Fragments, impacting Comp. B-filled projectiles, can initiate explosive reactions at velocities below that required for perforation of the projectile wall. This trend was noticed particularly when testing the thicker-walled projectiles.

4. For a given fragment impact mass (velocity), a greater velocity (mass) is required to initiate an explosive reaction for an impact at forty-five degrees obliquity than for an impact at zero degrees obliquity. This observation is based on a limited amount of data and may not be valid for all mass-velocity combinations.

B. Soviet Artillery and Rocket Projectiles

Because of a shortage of projectiles, only a few tests were conducted against the Soviet 57mm, 122mm, 140mm, and 152mm HE projectiles. The test results, presented in Tables B-I through B-IV, indicate that:

1. The Soviet projectiles tested are less vulnerable than U.S. Comp. B-filled projectiles of similar caliber. This may be attributed to both the thicker wall and the less sensitive HE filler of the Soviet projectiles.

2. Fragments, impacting either a 57mm, 122mm, or a 140mm HE projectile, did not initiate any explosive reactions at velocities below that required for perforation of the projectile wall. No wall perforations or explosive reactions were observed when fragment firings were conducted against the thicker-walled 152mm HE projectiles.

C. U. S. 81mm and Soviet/CHICOM 82mm Mortar Projectiles (TNT)

The Ballistic Research Laboratories have conducted tests to determine the vulnerability of both in-flight and stacked mortar ammunition to fragment attack. The results of these tests are presented in Tables C-I and C-II.

Both the 81mm and 82mm projectiles have a wall thickness of approximately 0.32 inches throughout most of their length. The major difference between the two projectiles is in the type of metal used in their manufacture. The domestic 81mm projectile casings are made of steel while the foreign 82mm projectile casings are made of cast iron.

Test results show that if an explosive or burning reaction is the objective of a fragment attack, the steel-cased projectiles are more vulnerable than those with cast iron casings. However, if the only purpose of attacking the projectile is to defeat it as an offensive weapon,

(dud the round) then the cast iron cased projectile is more vulnerable as it fractures more readily.

Although the fuze sections of projectiles contain the most sensitive elements, impacts on or near the fuzes in this test did not result in High Order reactions.

D. Firings against U.S. Sub-Missile Munitions

Table D-I presents the results of over 300 firings against five types of Sub-Missile munitions. It is observed that:

1. The five types of munitions tested are considered equally vulnerable to fragment impact.

2. Masking the rounds with a 0.63 inch aluminum sleeve and/or a 0.125 inch aluminum plate with or without a standoff, does not provide sufficient protection to significantly reduce round vulnerability to fragment impact.

A limited number of tests were conducted wherein 2.0 inches of polyurethane was placed between a 0.125 inch aluminum plate and a round with a 0.063 inch sleeve. No reduction in round vulnerability was observed.

Tests were also conducted against grouped XM-41 rounds in aluminum containers. The results of these tests, presented in Table D-II, show that if one round in the group detonates High Order, the remaining rounds will also detonate High Order.

(CONFIDENTIAL) V. EXPLOSIVE REACTIONS

The "Military Standard"[7] definition of a detonation is: "An exothermic chemical reaction that propagates with such rapidity that the rate of advance of the reaction zone into the unreacted material exceeds the velocity of sound in the unreacted material, that is, the advancing reaction zone is preceded by a shock wave. A detonation is classed as an explosion. The rate of advance of the reaction zone is termed detonation rate or detonation velocity. When this rate of

advance attains such a value that it will continue without diminution through the unreacted material, it is termed the stable detonation velocity. The exact value of this term is dependent upon a number of factors, principally the chemical and physical properties of the material. When the detonation rate is equal to or greater than the stable detonation velocity of the explosive, the reaction is termed a high order detonation. When the detonation rate is lower than the stable detonation velocity of the explosive, the reaction is termed a low order detonation."

Detonation rate measurements can be obtained in the laboratory when testing small quantities of bare explosive. Because of the elaborate instrumentation required to obtain detonation rate velocities, it is not feasible to collect such data in the field when testing HE-filled munitions.

When HE munitions are subjected to steel fragment impact, the results are usually classified as either High Order (HO), Low Order (LO), Burning (B), or No Reaction (NR). Some investigators have subdivided the Low Order and Burning reactions and labeled them High Low Order, Mild Low Order, Low Low Order, Prolonged Burning, etc. Test results are usually classified by personnel in the field on the basis of some predetermined criteria and are subjective in many cases.

The classifications of the results presented in this report are qualitative. No photographic, electronic or mechanical equipment was used to quantitatively measure the response. The Test Director in the field was required to classify the results as No Reaction (with or without perforation), Burning, Low Order or High Order.

Classification of results as No Reaction or Burning is straightforward and presents no problems. However, the rationale used for assessing results as High Order or Low Order requires some explanation.

It was observed, during the tests, that impacting steel fragments could perforate the wall of a steel-cased projectile leaving a well-defined hole. A visual inspection did not reveal any additional degradation

in the structural integrity of the projectile. When comparable projectiles, under similar impact conditions, fractured into two or more pieces, it was assumed that it was the result of an explosive reaction.

It was further assumed that the number and size of the projectile pieces were, in some sense, indicative of the magnitude of the explosive reaction. Explosive reactions were classified High Order if there was no evidence of large fragments and of unconsumed HE filler in the impact area. If any large pieces of the projectile or unconsumed HE were observed in the impact area, the test result was classified Low Order.

If a detonation rate criterion is the only accurate method of classifying test results as either High Order or Low Order, then it is possible that some of the explosive reactions classified High Order, in this report, should be reclassified Low Order.

These Laboratories have conducted tests[8] to determine the vulnerability of 30mm and 40mm HE gun systems to small arms attack. It was observed that 0.30, 0.50, and 0.60 caliber bullets, impacting at service velocity on the base of 30mm rounds, could detonate the 30mm projectile High Order. The criterion for a High Order reaction was complete fragmentation of the projectile and the complete consumption of all the HE filler. Additional tests were conducted wherein groups of rounds were taped together and one round was subjected to bullet impact. Test results indicated that some of the remaining rounds could sympathetically function Low Order. However, when one round in a group of rounds was statically detonated, all rounds in the group detonated High Order.

If we assume that statically detonated projectiles always detonate High Order, and that when one projectile in a group of projectiles detonates High Order the remaining projectiles will always sympathetically detonate High Order, then all the test results classified High Order in reference 8 as a result of bullet impact are suspect.

Using the response of witness rounds as a criterion for classifying explosive reactions as High Order or Low Order could prove to be a valid

technique. Unfortunately, range facility limitations and safety restrictions would limit the use of this technique to those tests involving the smaller caliber HE projectiles.

Until personnel in the field have the means of quantitatively as ing the magnitude of explosive reactions, at a reasonable cost, these test results classified High Order, in fragment or bullet impact tests conducted against HE munitions, are questionable and could easily be Low Order.

(CONFIDENTIAL) VI. ANALYSIS OF DATA

Test results were analyzed using several different methods. For a given projectile, the number of parameters investigated and the number of data points available for each parameter determined the method to be used. The methodology reflects both the utility and validity of analysis as a predictive tool.

The methods used in analyzing the vulnerability of each group of munitions are discussed in the following sections.

A. U. S. Artillery Projectiles

In this analysis, those test results classified High Order and Low Order were combined and treated as one phenomenon. This approach is justified on the bases that, for the area of primary interest, (i.e., thresholds for High Order and Low Order reactions), the impacting mass-velocity combinations were observed to be the same.

For each type of shell, the data is of the form (m_i, v_{ij}, d_{ij}), where

m_i is the mass of the fragment fired, $i = 1, 2, \ldots, M$.

v_{ij} is the corresponding velocity for each i, $j = 1, 2, \ldots, N$.

d_{ij} is the corresponding result of the test, $d_{ij} = 0$ or 1,

that is, $d_{ij} = 0$ when a fragment of mass m_i, fired at a velocity v_{ij} resulted in no detonation, and $d_{ij} = 1$ when the fragment impact resulted in a detonation.

An adequate model for this type of experiment is described by Golub and Grubbs[9]. The assumptions and techniques are described in reference 9 and will not be repeated here. With this method, for each shell and each fragment of mass m_i, (v_{ij}, d_{ij}) are used to obtain $\bar{V}_i$, $\hat{\sigma}_i^2$, $\hat{\sigma}^2_{\bar{V}_i}$, $\hat{\sigma}^2_{\sigma_i}$ where

- $\bar{V}_i$ (commonly called $V_{.5}$) is an estimate of the mean velocity μ_i corresponding to m_i with the property that a projectile of mass m_i fired at the given shell with a velocity of μ_i will detonate the shell 50% of the time.
- $\hat{\sigma}_i^2$ is an estimate of the variance σ_i^2.
- $\hat{\sigma}^2_{\bar{V}_i}$ is the approximate variance of the estimate $\bar{V}_i$.
- $\hat{\sigma}^2_{\sigma_i}$ is the approximate variance of the estimate s_i^2.

One assumption of the model is that the probability of detonation p is given by

$$p = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} \exp(-t^2/2)\,dt \tag{1}$$

where

$$t = \frac{V - \mu}{\sigma}$$

Since, for each shell and each fragment mass m_i, $\bar{V}_i$ and $\hat{\sigma}_i^2$ are maximum likelihood estimates of μ and σ^2, one can construct a probability function based on the assumption of normality and the estimates.

Preliminary analysis of the data using median velocity values (see Table A-V through A-IX) for each type of shell indicate that mass versus velocity plots for each shell would be hyperbolic. Therefore, a curve of the form $\bar{V}^h = K/m$ was fit to the data corresponding to each shell,

namely, h and K were to be estimated for each shell. Because of the small number of data points used to fit each curve, it was decided that only one parameter should be estimated. Since h = 3 was a good representative value for the power of $\overline{V}$ over all fits, we fixed the value of h at 3 and estimated K only.

For each shell, a curve

(2) $$\overline{V}^3 = K/m$$

was fit using the method of Least Squares and the Data points $(m_i, \overline{V}_i)$, $i = 1, \ldots, n$. K was chosen so that

(3) $$\sum_{i=1}^{n} (\overline{V}_i - (K/m)^{1/3})^2$$

was a minimum. The solution is

(4) $$K = \left[\frac{\sum_{i=1}^{n} \overline{V}_i \; m_i^{-1/3}}{\sum_{i=1}^{n} m_i^{-2/3}}\right]^3$$

For each shell, eq. (2) gives an estimate of $\overline{V}$ $(V_{.5})$ as a function of the mass of the projectile.

For each shell and each $\overline{V}_i$ corresponding to m_i, $\hat{\sigma}^2_{\overline{V}_i}$, an approximate variance of the estimate $\overline{V}_i$, was used as a weighting factor in a second fit of the curve $\overline{V}^3 = K'$ so that

$$\sum_{i=1}^{n} w_i \; (\overline{V}_i - (K'/m)^{1/3})^2$$

is a minimum, where

$w_i = 1/\sigma^2_{\overline{V}_i}$. The minimizing value of K' is

$$K' = \left[\frac{\sum_{i=1}^{n} w_i \overline{V}_i m^{-1/3}}{\sum_{i=1}^{n} w_i m_i^{-2/3}} \right]^3$$

The second fit of the data, using the weights, would appear to be a reasonable criterion. For a data point (m_i, $\overline{\ }$) where the $\sigma^2_{\overline{V}_i}$ is small, indicative of a more reliable estimate, the weight is large, thus forcing the curve close to the point. Similarly, for data point (m_i, $\overline{V}_i$) where the $\sigma^2_{\overline{V}_i}$ is large, indicative of a less reliable estimate, the weight is small, thus permitting the curve to miss the data point by more. Thus the estimates for the fits using the weighted criterion will be closer to the points which have lower confidence than the corresponding estimates for the fits using equation (4). These data are presented in tabular form in Table II.

The results of this analysis were used to establish a protection coefficient "K" for Comp. B-l(led artillery projectiles. This technique developed by F. C. Ledsham is discussed in detail in the British Ordnance Board report.[6]

The protection coefficient is defined as:

$$(5) \qquad K = \frac{(V - V_o)\, d}{V_o \quad x}$$

where

TABLE II (C). CLASSIFICATION OF RESULTS
Impacting Mass-Velocity Combinations Required To Explosively Function U.S. Artillery Projectiles (Composition B) 50% of the Time (U)

Projectile Type	Impacting Mass (grains)	Impacting Velocity (mps)						
		Golub and Grubbs						Median Values from Firing Record
		$\bar{V}_{.5}$	σ	$\sigma_{\bar{V}}$	σ_{σ}	Least Squares	Weighted Least Squares	
90mm	30					2582*	2558*	
	60	2147	100	40	49	2049	2030	2126
	120	1552	52	28	36	1626	1611	1570
	240	1267	43	19	18	1291	1271	1334
105mm	30	3054	674	427	569	2650	2630	2666
	60	1808	90	29	43	2103	1873	1563
	120	1479	117	46	90	1669	1486	1453
	240	1224	48	20	39	1325	1180	1228
155mm	30					2586*	2560*	
	60					2053*	2063*	
	120	1598	85	31	34	1629	1638	1697
	240	1333	72	25	33	1293	1300	1372
175mm	30					3003*	2837*	
	60					2383*	2252*	
	120	1968	332	113	226	1892	1788	1878
	240	1405	92	28	29	1501	1418	1423

* Extrapolated values.

NOTE: This Table was generated by combining data from High Order and Low Order reactions.

V = striking velocity (mps) that a cylindrical steel fragment, impacting face-on, required to detonate a Comp. B-loaded artillery projectile 50 percent of the time.

V_o = the striking velocity (mps) that the same fragment, impacting face-on, required to detonate High Order bare Comp. B 50 percent of the time. These data were taken from a report by Slade and Dewey (see Figure 5).

d = the diameter of the fragment in inches.

x = projectile wall thickness in inches at the point of impact.

Protection coefficients were generated for all the U.S. projectiles using eq. (5) and are presented in Table III.

To arrive at a generalized solution for these projectiles, the weighted least squares data was averaged and found to be 0.740. Setting K = 0.740 and solving

$$V = \frac{V_o\,(Kx + d)}{d} \tag{6}$$

predictive curves were generated for each projectile. Figures 6 through 9 show these predictive curves together with the weighted least squares curves for High Order and Low Order reactions and least squares curves for perforation of the projectile wall.

Assuming normality of data and using the $V_{.5}$ and σ values generated via the Golub and Grubbs Analysis, it was possible to construct cumulative probability distributions in most cases. These distributions are illustrated in Figures 10 through 13 and provide some guidance in predicting the changes in striking velocity required to detonate a projectile for probabilities of detonation other than 0.5.

B. Soviet Artillery Projectiles

Because of the limited data available, estimates of the vulnerability of the 57mm, 122mm and 140mm projectiles were made using a residual velocity criterion. An analysis of all the data for these rounds shows that no explosive reactions, High or Low Order, were observed until the striking velocity of the fragment exceeded that required for perforation. Using

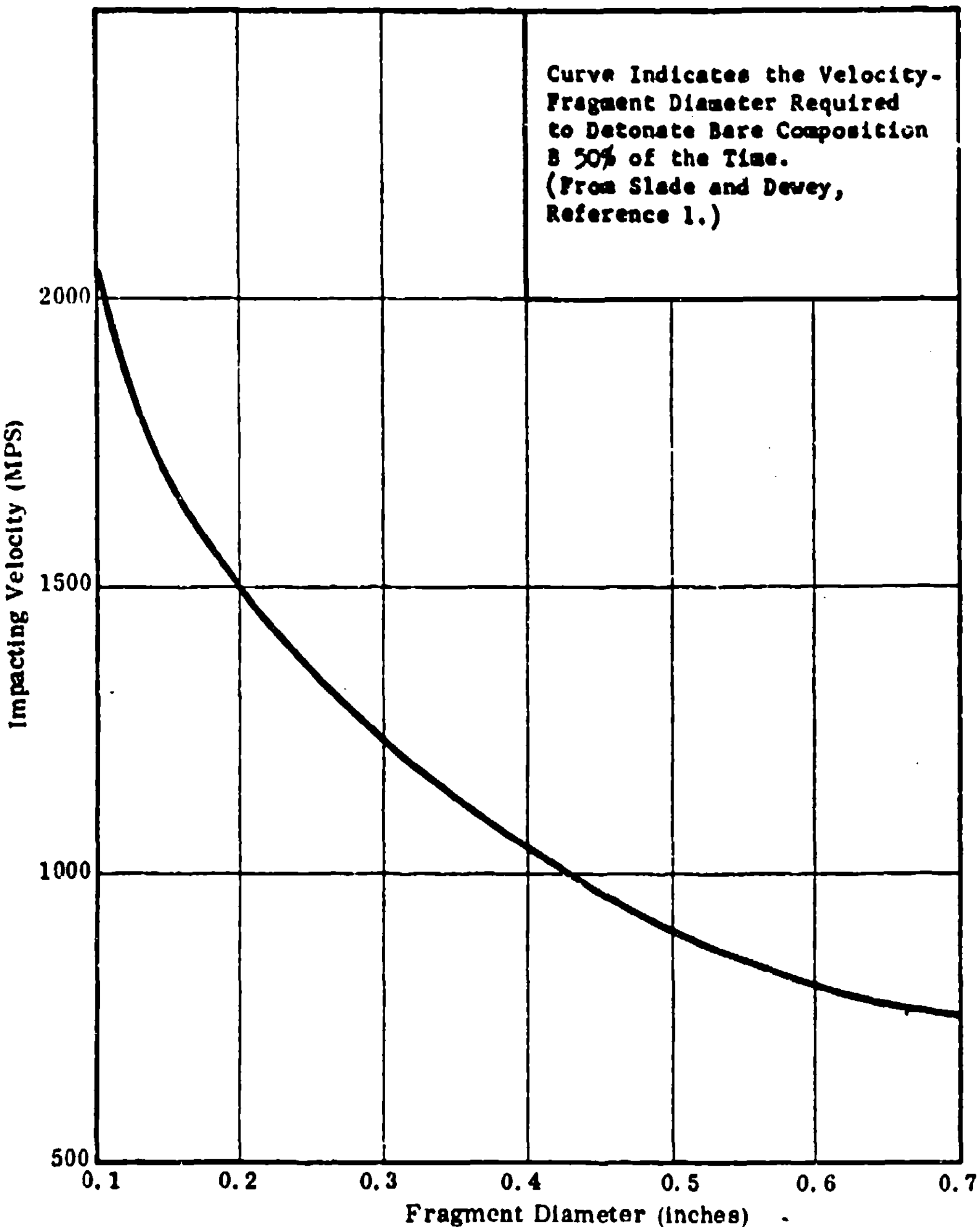


Figure 5 (C). Vulnerability of Bare Composition B to Cylindrical Fragment Impact (U)

TABLE III (C). Protection Coefficients for U.S. Artillery Projectiles (Comp B) (U)

Projectile Type	Striking Mass Grains	Median Values	Golub and Grubbs	Least Squares	Weighted Least Squares
90mm	30	no data	no data	.708*	.695*
	60	.843	.859	.782	.757
	120	.736	.683	.799	.782
	240	.764	.665	.700	.682
105mm	30	.904	1.144	.894	.715
	60	.766	.714	.992	.775
	120	.728	.763	1.020	.773
	240	.729	.723	.903	.642
155mm	30	no data	no data	.615*	.662*
	60	no data	no data	.681*	.626*
	120	.712	.664	.696	.706
	240	.761	.661	.632	.645
175mm	30	no data	no data	.854*	.775*
	60	no data	no data	.965*	.870*
	120	1.000	1.093	1.014	.906
	240	.829	.804	.937	.823

*Coefficients were generated from extrapolated data.

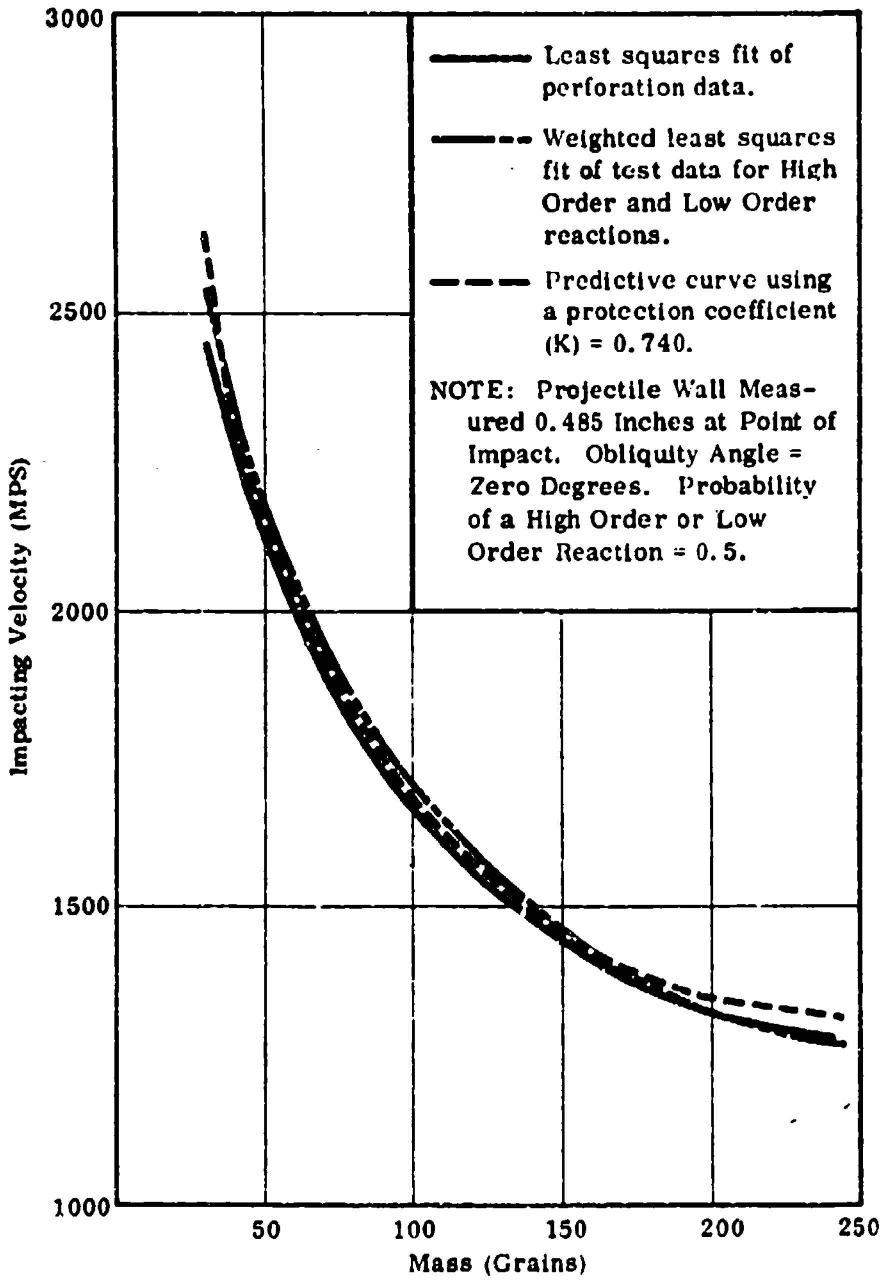


Figure 6 (C). Vulnerability of the U.S. 90mm HE Projectile (Composition B) to Fragment Impact (U)

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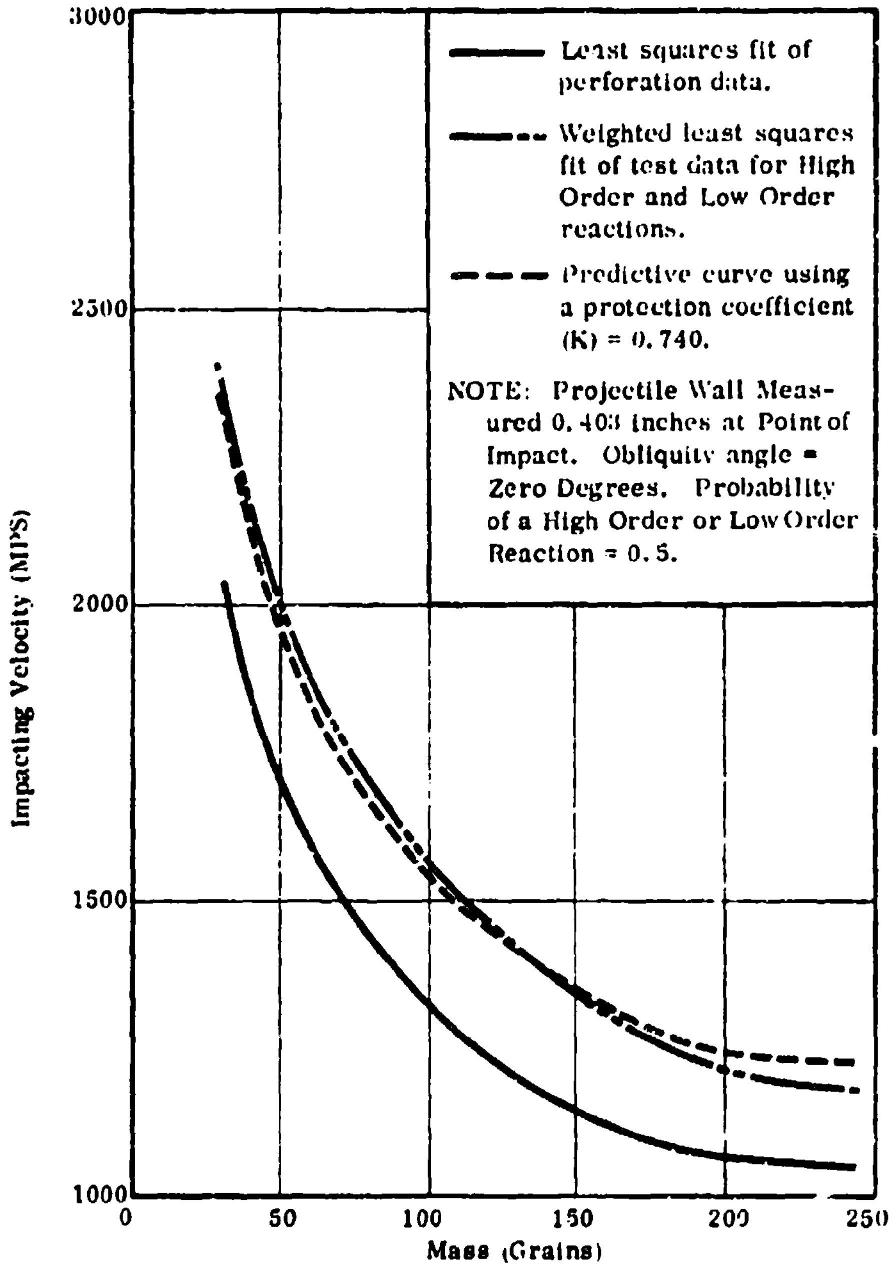

Figure 7 (C). Vulnerability of the U.S. 105mm HE Projectile (Composition B) to Fragment Impact (U)

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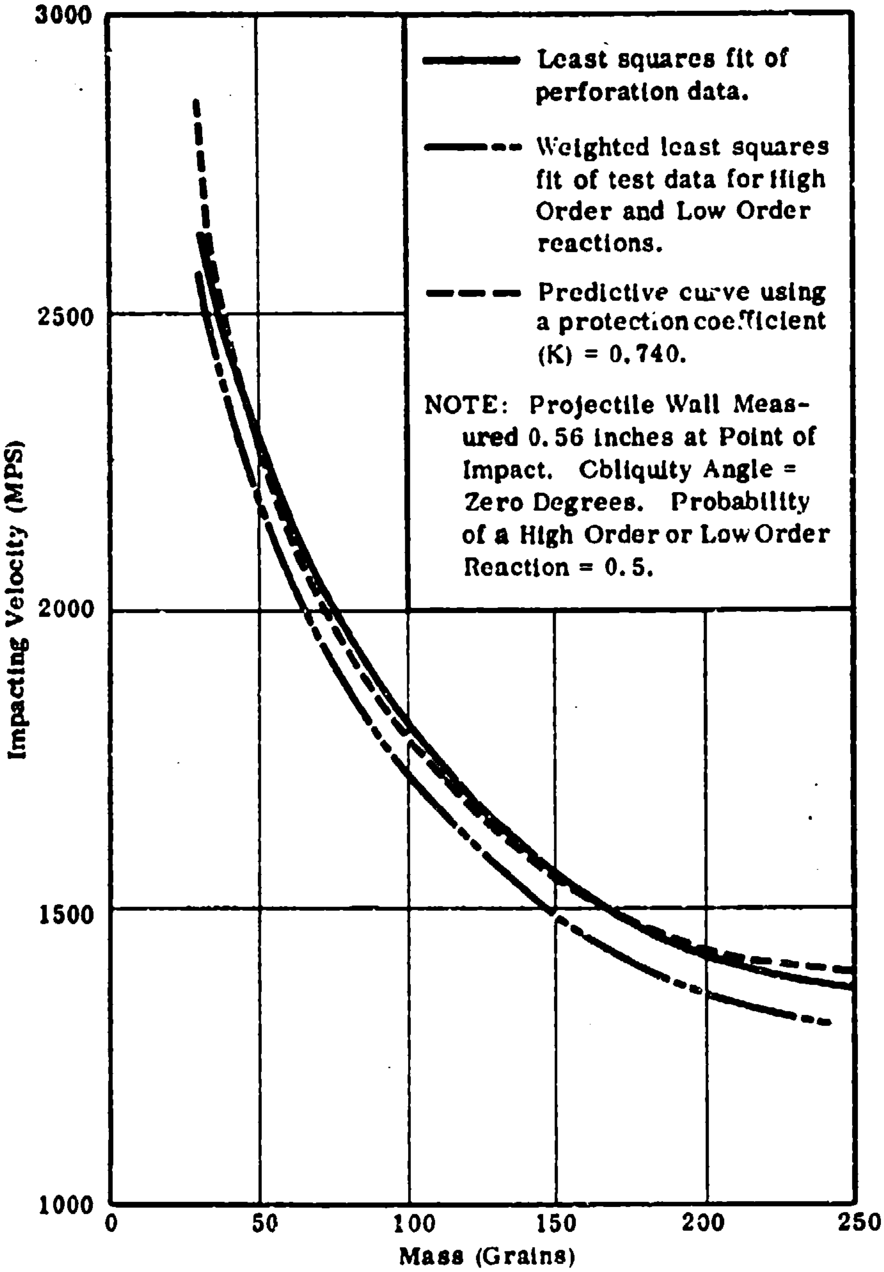

Figure 8 (C). Vulnerability of the U.S. 155mm HE Projectile (Composition B) to Fragment Impact (U)

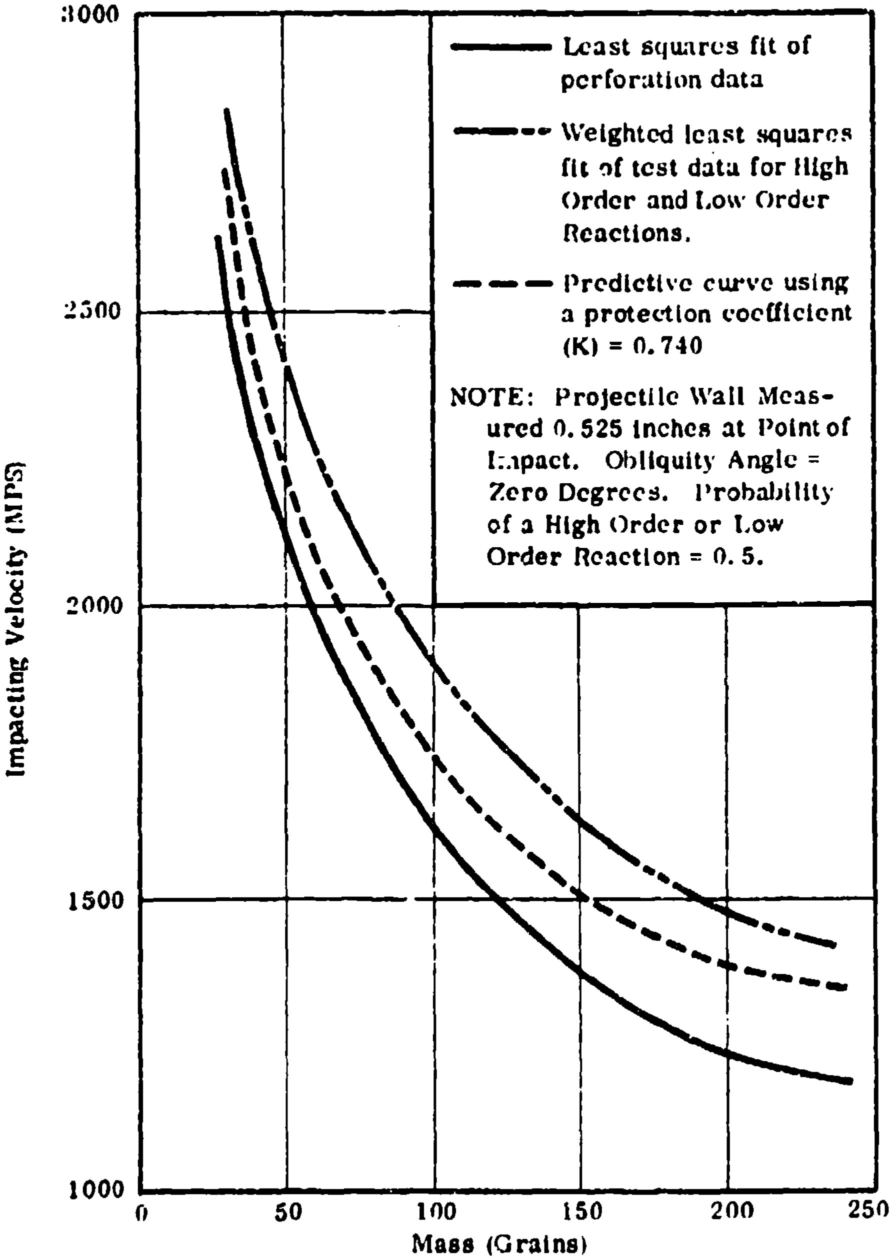

Figure 9 (C). Vulnerability of the U.S. 175mm HE Projectile (Composition B) to Fragment Impact (U)

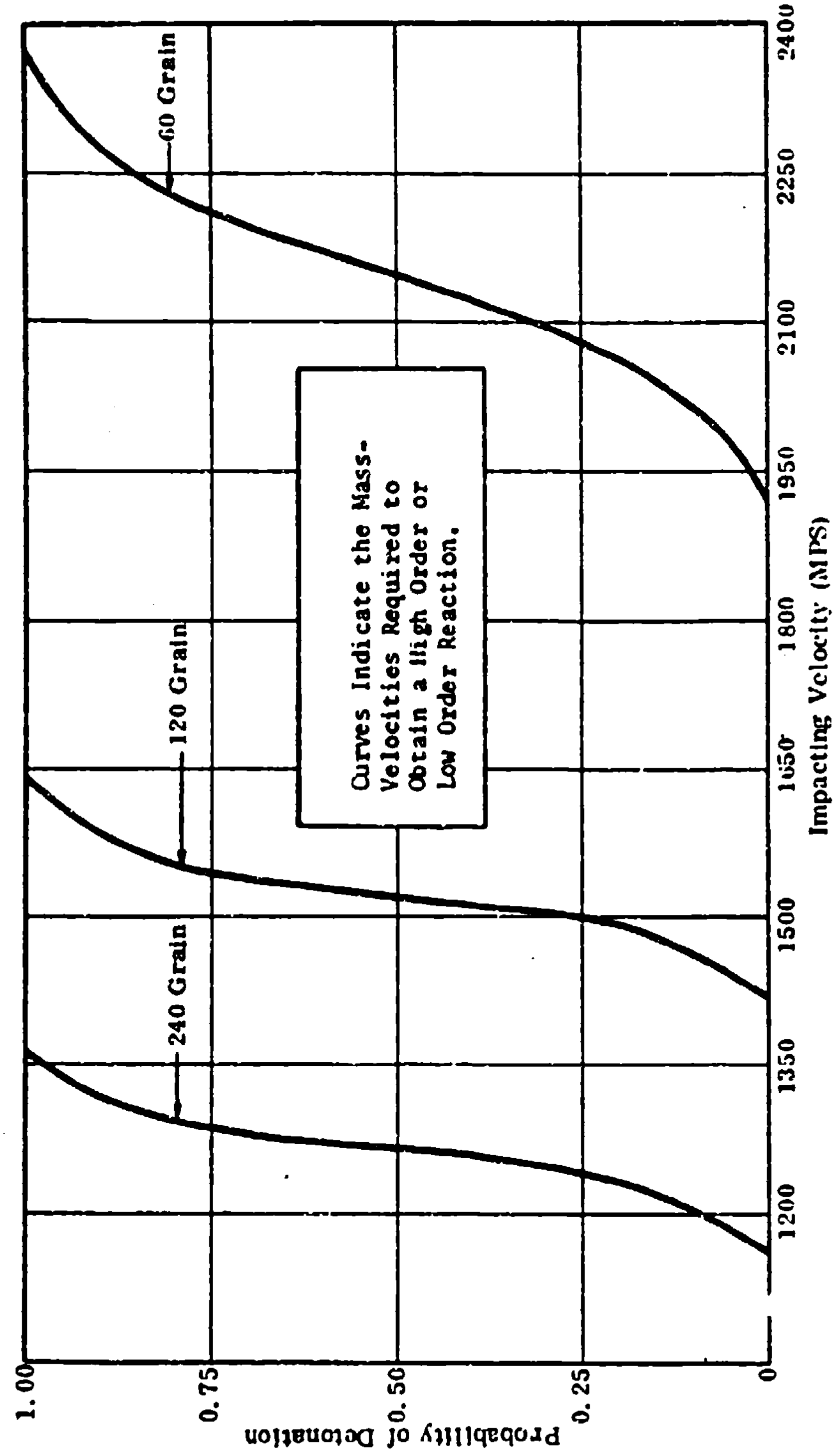

Figure 10 (C). Cumulative Probability Distributions for the U.S. 90mm HE Projectile (Comp. B) (U)

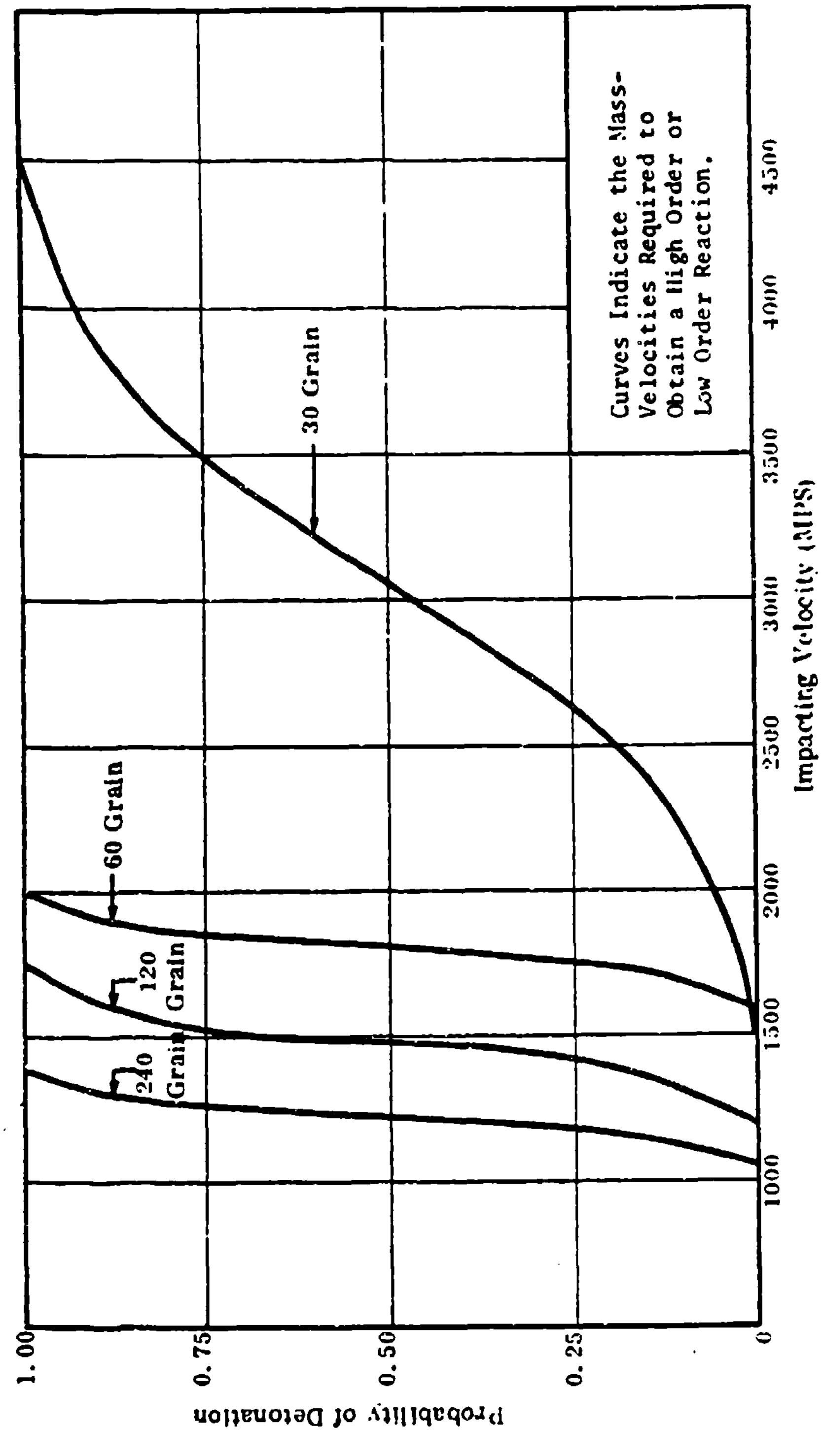

Figure 11 (C). Cumulative Probability Distributions for the U.S. 105mm HE Projectile (Comp. B) (U)

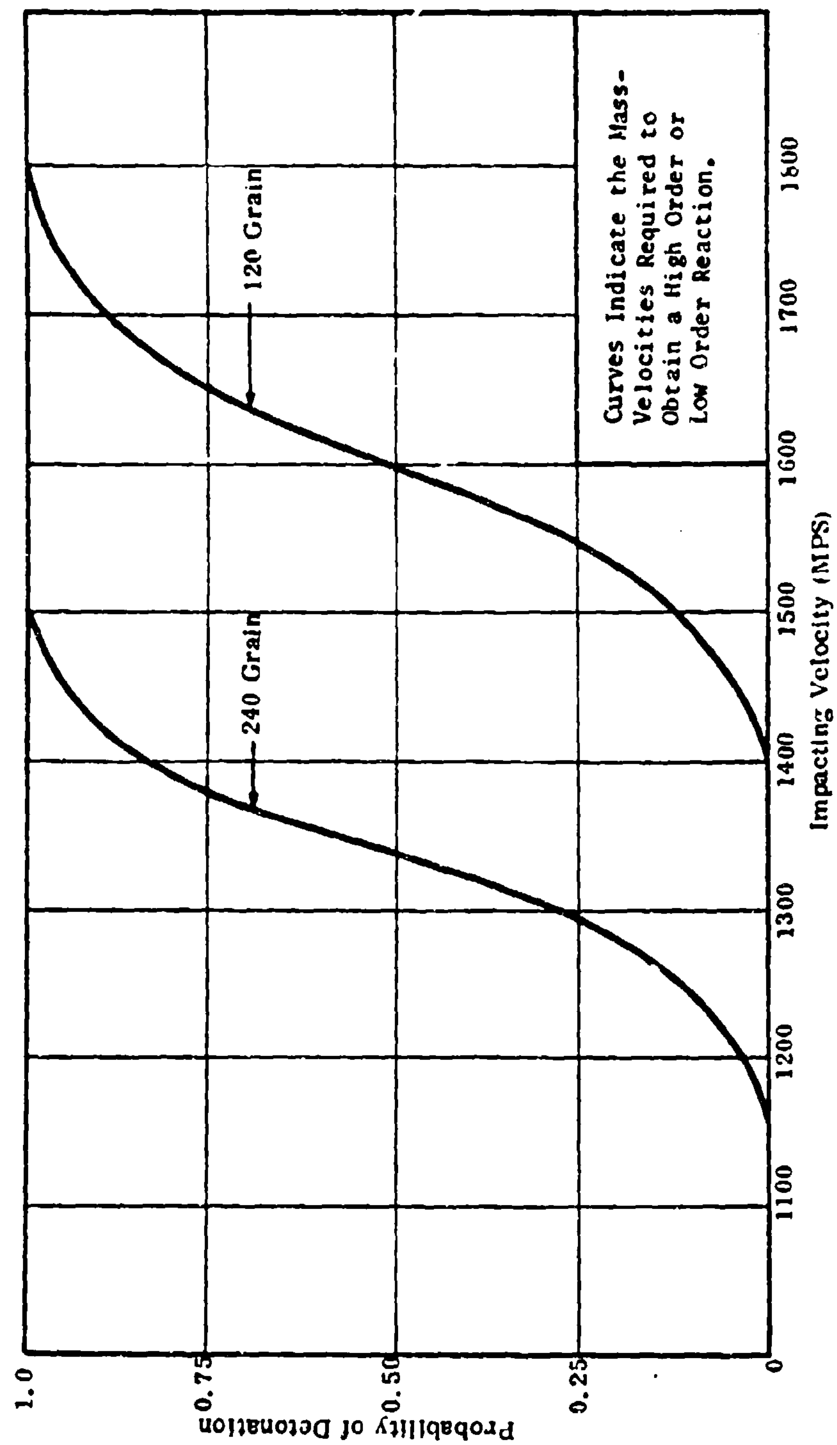

Figure 12 (C). Cumulative Probability Distributions for the U.S. 155mm HE Projectile (Comp. B) (U)

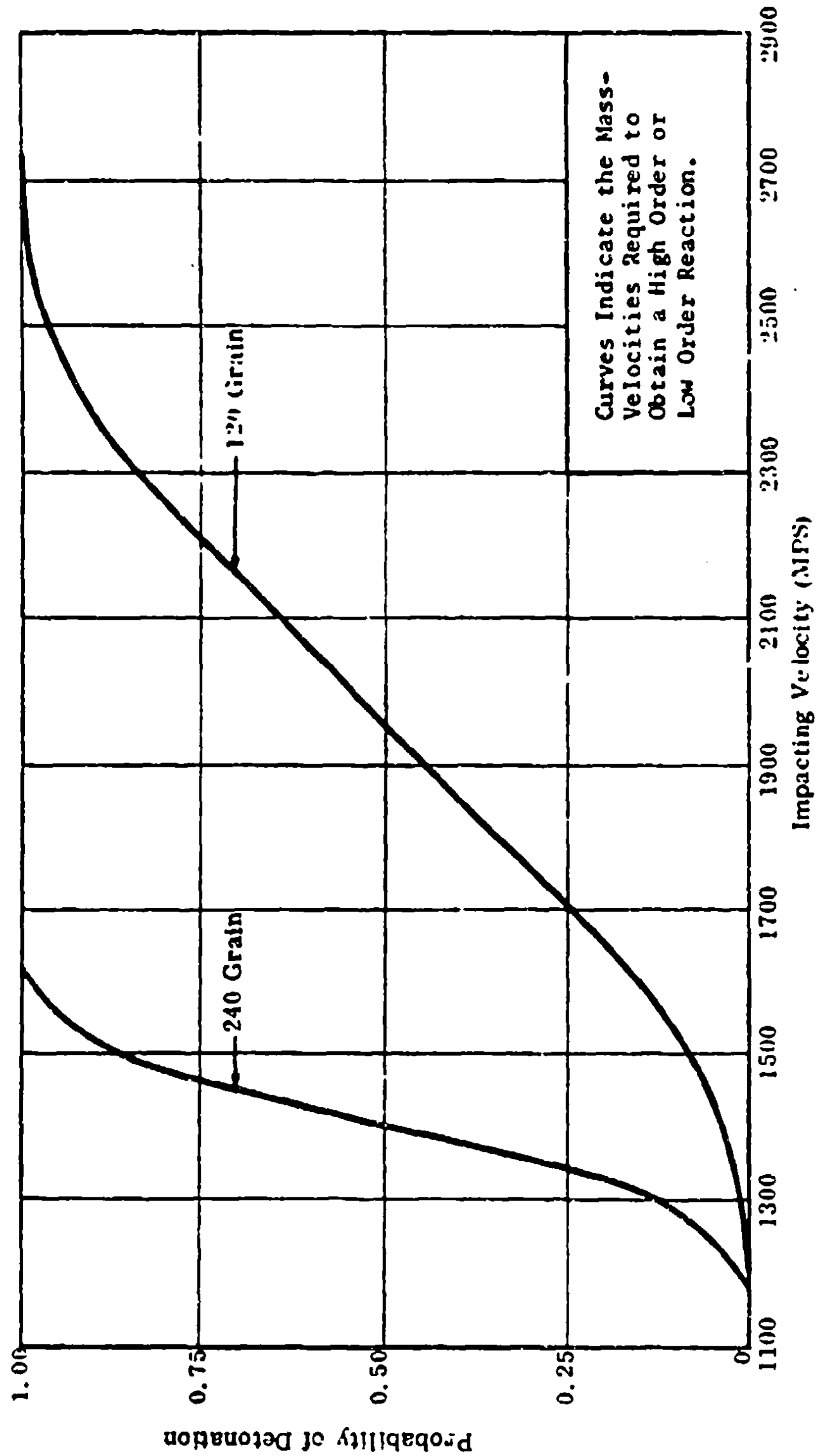

Figure 13 (C). Cumulative Probability Distributions for the U.S. 175mm HE Projectile (Comp. B) (U)

all the projectile perforation data available and the firing records for these rounds, the following velocity criterion was established for each round

	60 gr	120 gr	240 gr
57mm	750 mps	600 mps	500 mps
122mm	400 mps	300 mps	275 mps
140mm	1000 mps	800 mps	700 mps

These velocities are estimates of the minimum velocities required by the fragments, after perforating the projectile wall, to initiate a Low-Order reaction 50% of the time. The predictive curves for these rounds are presented in Figures 14, 15, and 16.

It was not possible to make any predictions on the vulnerability of the 152mm projectile. None of the fragments fired against this round were able to perforate the projectile wall. The .50 cal bullet impacting at service velocity (869 mps) initiated a Low Order reaction.

C. U.S. 81mm and Soviet/CHICOM 82mm Mortar Projectiles

The experimental data for these two mortar projectiles result from two ad hoc tests conducted at these Laboratories and are included in this report for comparative purposes. The objective of the first test was to determine the vulnerability of stacked mortar ammunition in wooden boxes to fragment impact. The second test was conducted to establish the in-flight vulnerability of the round. Both tests were limited and it was not possible to generate a predictive curve for the Soviet/CHICOM 82mm round. An estimated vulnerability curve for the U.S. 81mm mortar projectile based on the two data points available is presented in Figure 17.

D. U.S. Sub-Missile Munitions

Considerable data were generated during this series of tests. The 30 grain high density fragments were used to satisfy an additional requirement and the data are included for comparative purposes only.

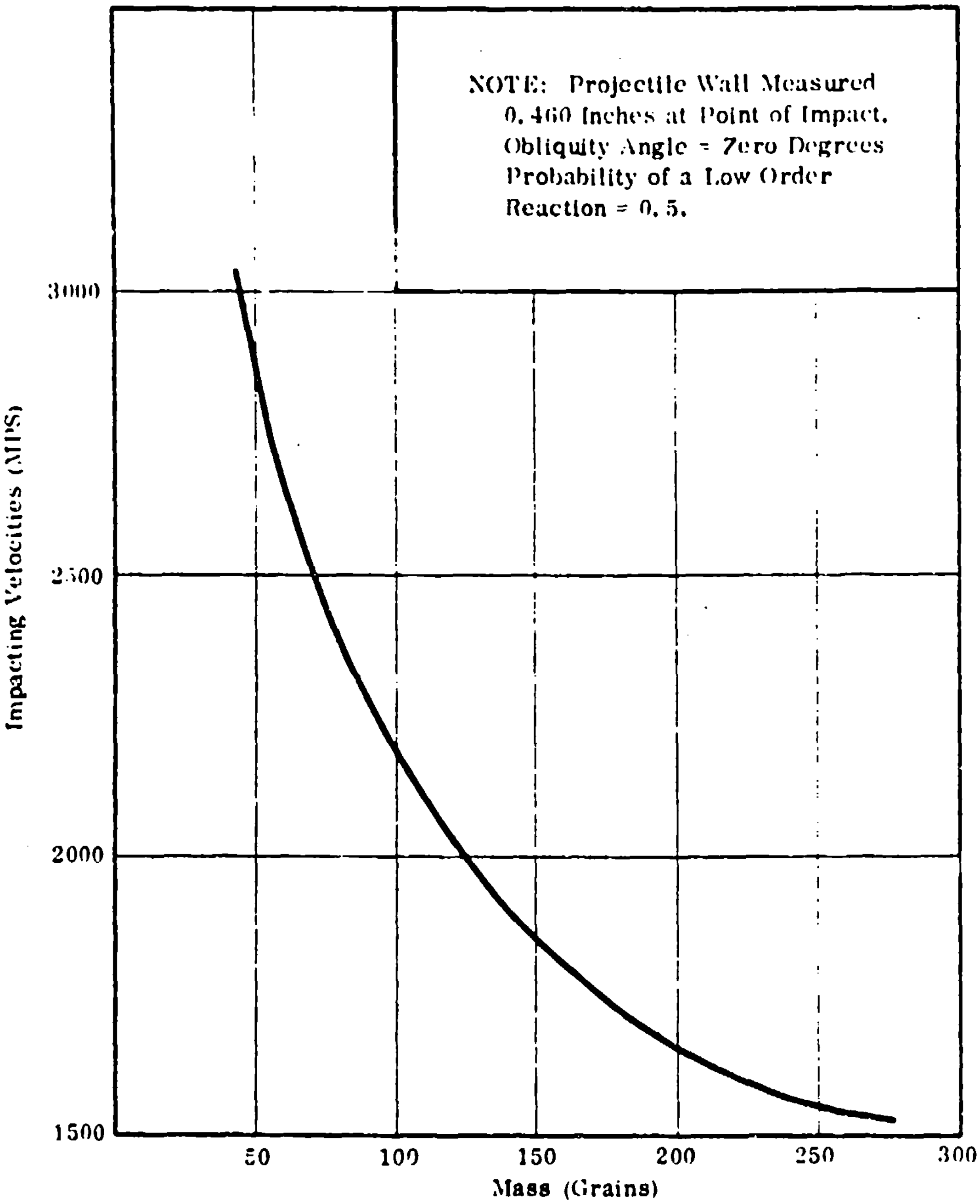

Figure 14 (C). Vulnerability of the Soviet 57mm HE Projectile (RDX/aluminum) to Fragment Impact (U)

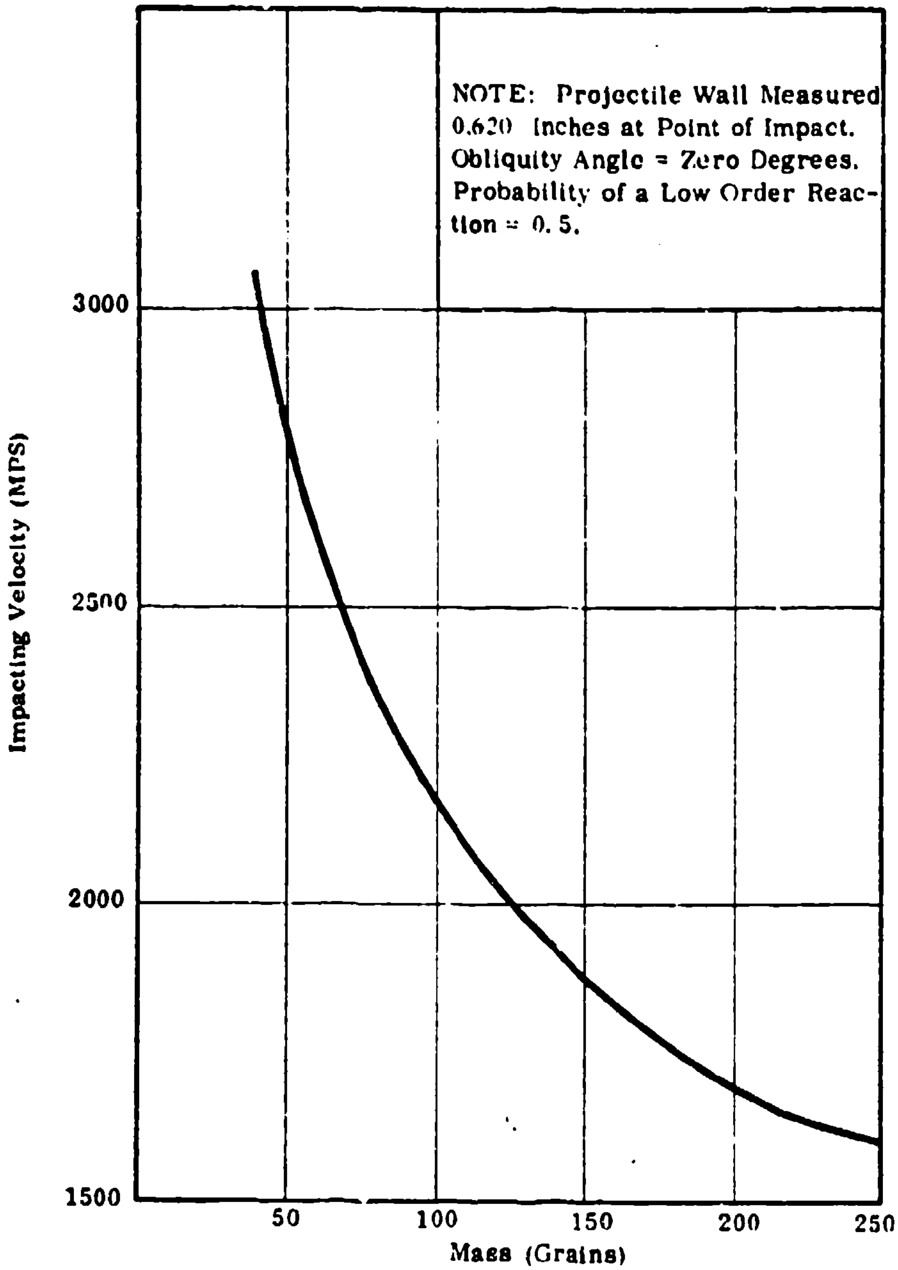

Figure 15 (C). Vulnerability of the Soviet 122mm HE Projectile (TNT) to Fragment Impact (U)

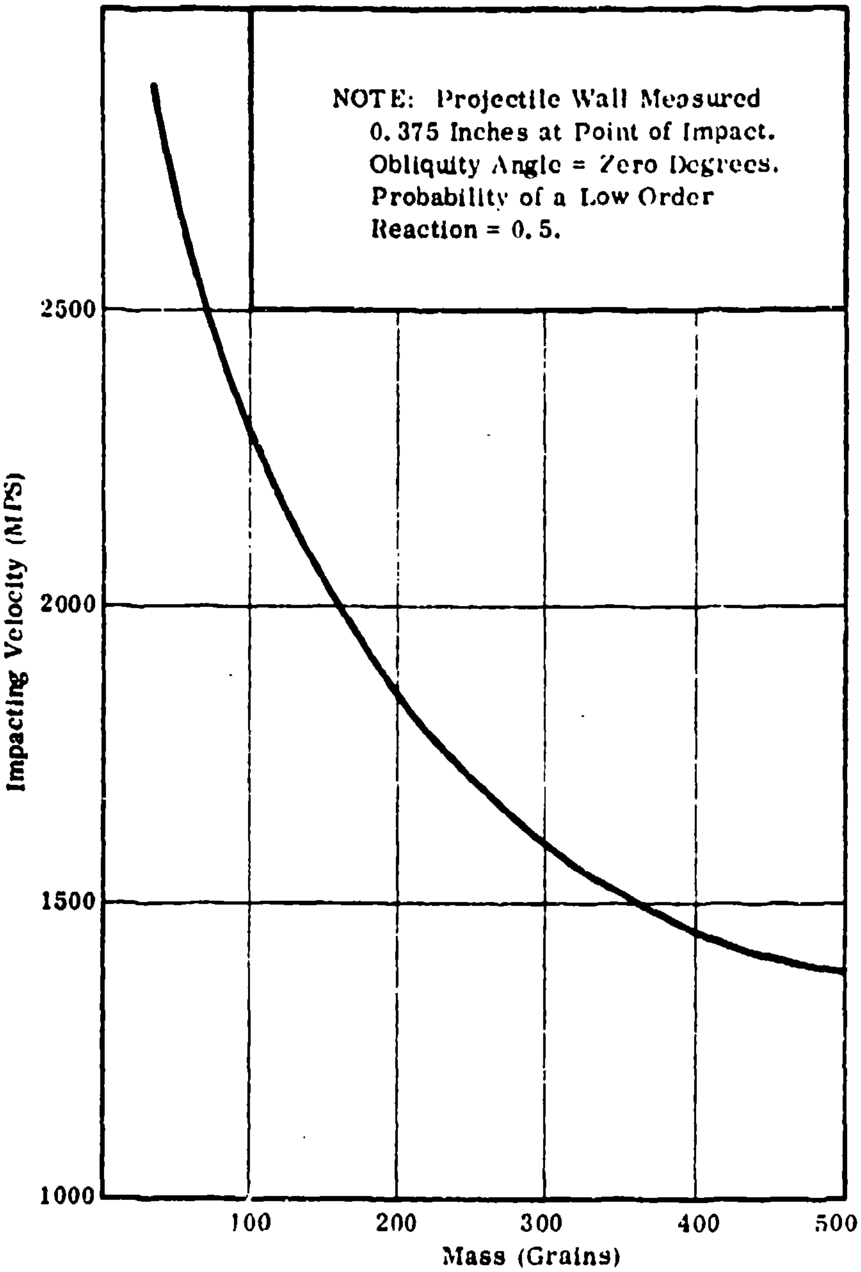

Figure 16 (C). Vulnerability of the Soviet 140mm HE Rocket Projectile (TNT) to Fragment Impact (U)

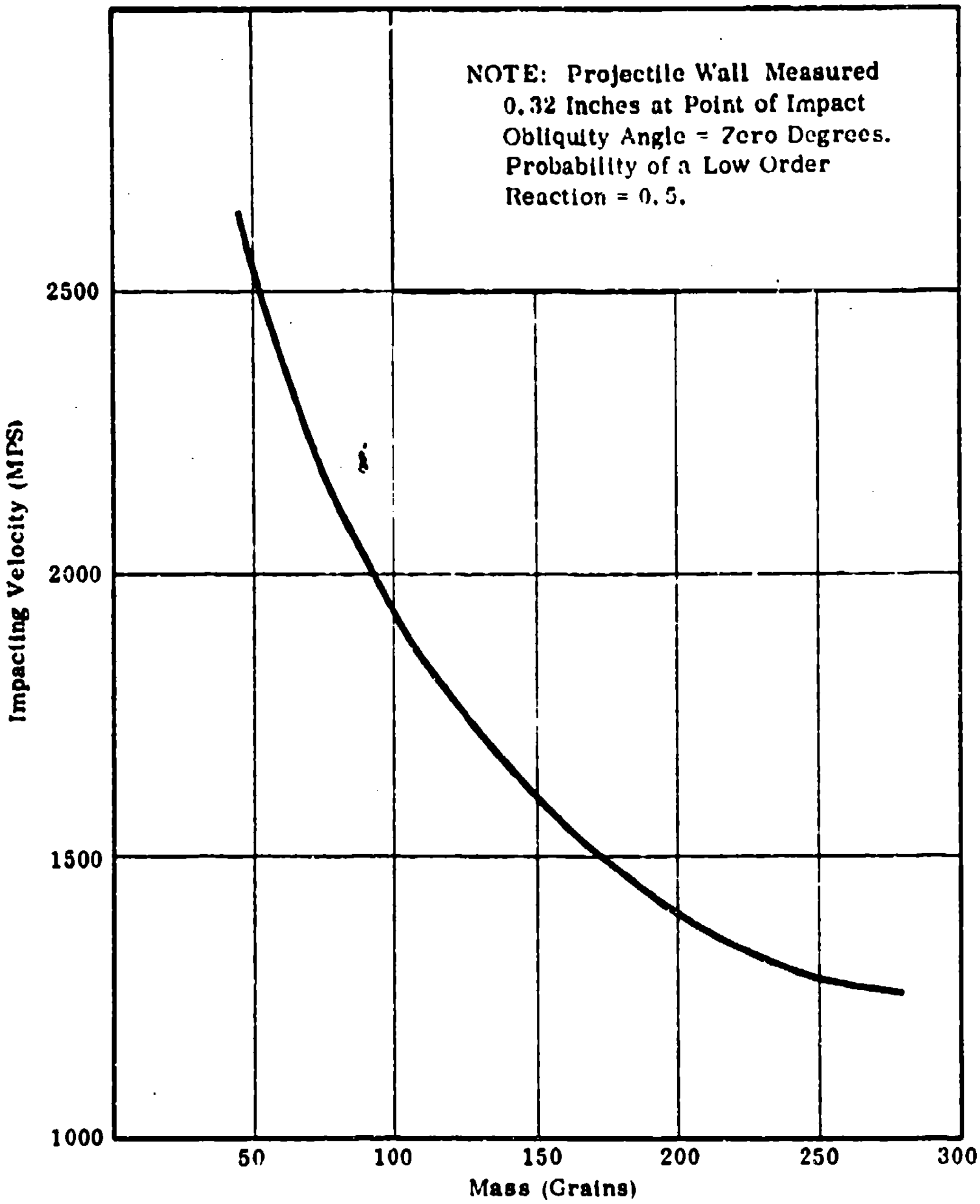

Figure 17 (C). Vulnerability of the U.S. 81mm Mortar Projectile (TNT) to Fragment Impact (U)

The median value, of the impacting velocities, each fragment required for each type of reaction is grouped by munition type for all impact conditions in Table IV. The same median value data are grouped by impact conditions for all munition types in Table V. The number in parentheses following the median values in both Tables IV and V is the number of observations used in arriving at the median values.

An examination of the data in Table V indicates that the five types of munitions tested can be considered equally vulnerable to fragment impact. Therefore, the data were combined and an analysis was made independent of munition type.

The median values presented in Table VI were reduced from these combined data using High Order values only. The $\bar{V}_{.5}$ and σ values were computed using the Golub and Grubbs technique and classifying both the Low Order and ruptured case results as the no detonation case, i.e., $d_{ij} = 0$. Curves were fit to the median value data for all three impact conditions, see Figure 18.

Because of the physical size and shape of these rounds, these Laboratories believe that the vulnerability curves in Figure 18 are valid for all obliquity angles up to ricochet.

(CONFIDENTIAL) VII. CONCLUSIONS

All types of conventional HE-filled munitions are vulnerable to steel fragment impact. The response of a particular round to fragment impact is a function of the following parameters.

A. Fragment Characteristics

The impacting mass, velocity and shape all influence the way in which a round will respond. However, it is not known which of these three parameters is predominant.

B. Projectile Characteristics

There is a steady decrease in the vulnerability of steel HE projectiles as the wall thickness increases. Limited tests indicate

TABLE IV (C).CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Target Type (U)

Target Type	Spacing (inches)	Aluminum Shielding (Inches)	Fragment Weight (grains)	Median Velocities (mps)		
				RC[a]	LO[b]	HO[c]
M-32	0	0	30HD[d]	2583(1)[e]	2503(6)	2671(5)
M-32	0	0.125[f]	30HD	2354(1)	2474(6)	2643(5)
M-32	1.875	0.125	30HD		2153(3)	
M-32	2.000	0.125	30HD	2655(2)	2526(17)	2679(3)
M-40	0	0	30HD	1688(1)	2283(2)	2476(3)
M-40	0	0.125	30HD	2697(1)	2534(7)	2628(5)
M-40	1.875	0.125	30HD	2038(4)	2603(10)	
M-40	0	0	60			2016(4)
M-40	0	0.125	60		1859(2)	2033(4)
M 40	1.750	0.125	60		1850(2)	2245(2)
M 40	1.875	0.125	60		2204(4)	2340(2)
M-40	0	0	120			1222(3)
M-40	0	0.125	120		1509(7)	1702(9)
M-40	1.750	0.125	120		930(1)	1889(1)
M-40	1.875	0.125	120		1657(4)	1632(6)
M-40	0	0	240		980(5)	1109(5)
M-40	0	0.125	240		917(7)	1126(3)
M-40	1.875	0.125	240		925(5)	1372(11)

a. RC = Ruptured Case
b. LO = Low Order Reaction
c. HO = High Order Reaction
d. 30 HD = 30 grain high density steel, remainder of fragments are mild steel.
e. The number of data points used in generating the median value.
f. 0.125 plate, 0.063 sleeve, 2.0 inch polyurethane or combinations of all three.

TABLE IV (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Target Type (Continued) (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps)		
				RC[a]	LO[b]	HO[c]
M-42E1	0	0.125	30			23[illegible]0(4)
M-42E1	1.570	0.125	30			2469(3)
M-42E1						
M-42E1	0	0.125	60			1552(3)
M-42E1	1.570	0.125	60		20[illegible](2)	19[illegible](1)
M-42E1	0	0	120			129[illegible](6)
M-42E1	1.570	0.125	120			1630(3)
M-42E1	0	0	240			1031(6)
M-42E1	1.570	0.125	240		[illegible](3)	
XM-41	0	0.125	30HD			2[illegible]5(4)
XM-41	0	2.188	30HD			2[illegible]30(1)
XM-41	0	0.125	60		192[illegible](2)	200[illegible](2)
XM-41	0	2.188	120		1817(1)	1[illegible](4)
XM-41	0	2.188	240			1911(4)
XM-42	0	0	30HD	1553(1)	2243(5)	23[illegible](10)
XM-42	0	0.125	30HD		230[illegible](1)	2448(7)
XM-42	0	2.188	30HD			2[illegible]4(1)
XM-42	0	0	60		13[illegible]2(4)	15[illegible]4(8)
XM-42	0	0.125	60		1[illegible](2)	18[illegible](2)
XM-42	0	0.188	60		2001(5)	22[illegible]2(4)
XM-42	1.5[illegible]	0.188	[illegible]	2264(2)	22[illegible](2)	24[illegible](5)

TABLE IV (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Target Type (Continued) (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps)		
				RC[a]	[illegible][b]	[illegible][c]
XM-42	0	0.063	120		1203(4)	136[illegible]([illegible])
XM-42	0	0.188	120		1652(4)	1[illegible](3)
XM-42	1.570	0.188	120		1[illegible]23(4)	1[illegible](4)
XM-42	0	0	240		[illegible]49(2)	10[illegible](4)
XM-42	0	0.125	240		975(3)	106[illegible](2)
XM-42	1.570	0.125	240		[illegible]92(3)	116[illegible](3)

TABLE V (C).CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Impact Conditions (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps) RC[a]	LO[b]	HO[c]
M-32	0	0	30HD[d]	2563(1)[e]	2383(6)	2671(5)
M-40	0	0	30HD	1666(1)	2263(2)	2476(3)
M-42	0	0	30HD	1593(1)	2243(5)	2360(10)
M-32	0	0.125[f]	30HD	2354(1)	2474(1)	2643(5)
M-40	0	0.125	30HD	2697(1)	2534(7)	2625(5)
XM-41	0	0.125	30HD			2505(4)
XM-42	0	0.125	30HD		2304(1)	2445(7)
XM-41	0	2.188	30HD			2630(1)
XM-42	0	2.188	30HD			2674(1)
M-32	1.875	0.125	30HD		2163(3)	
M-40	1.875	0.125	30HD	2036(1)	2603(10)	

a. RC = Ruptured Case
b. LO = Low Order Reaction
c. HO = High Order Reaction
d. 30HD = 30 Grain high density steel, remainder of fragments are mild steel
e. The number in parentheses following the median value indicates the number of data points used in generating the median value.
f. 0.125 = An aluminum plate 0.125 inches thick
   0.063 = An aluminum sleeve 0.063 inches thick.
   0.188 = Combination of 0.063 sleeve and 0.125 plate
   2.188 = Combination of 0.063 sleeve, 0.125 plate and 2.0 inches Polyurethane

TABLE V (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Impact Conditions (Continued) (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps) RC[a]	LO[b]	HO[c]
M-32	2.0	0.125	30HD	2655(2)	2629(17)	2679(3)
M-42E1	0	0.125	30			2350(4)
M-42E1	1.570	0.125	30			2469(3)
M-40	0	0	60		1372(4)	2016(4)
XM-42	0	0	60		1372(4)	1584(8)
M-40	0	0.125	60		1869(2)	2033(4)
X-42E1	0	0.125	60			1882(3)
XM-41	0	0.125	60		1926(2)	2008(2)
XM-42	0	0.125	60		1887(2)	1898(2)
XM-42	0	0.188	60		2091(5)	2292(4)
M-42E1	1.570	0.125	60		2056(2)	1968(1)
M-40	1.750	0.125	60		1860(2)	2245(2)
M-40	1.875	0.125	60		2204(4)	2340(2)
XM-42	1.570	0.188	60	2264(2)	2288(2)	2498(5)
M-40	0	0	120			1222(3)
M-42E1	0	0	120			1298(6)
XM-42	0	0.063	120		1203(4)	1362(8)
M-40	0	0.125	120		1509(7)	1702(9)
XM-42	0	0.188	120		1682(4)	1809(3)
XM-41	0	2.188	120		1817(1)	1965(4)

TABLE V (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions
Median Values Grouped by Impact Conditions (Continued) (U)

Target Type	Spacing (inches)	Aluminum Shielding (inches)	Fragment Weight (grains)	Median Velocities (mps)		
				RC[a]	LO[b]	HO[c]
M-42E	1.570	0.125	120			1630(3)
M-40	1.750	0.125	120		980(1)	1889(1)
M-40	1.875	0.125	120		1657(4)	1632(6)
XM-42	1.570	0.188	120		1823(4)	1908(4)
M-40	0	0	240		980(5)	1109(5)
M-42E1	0	0	240			103'(6)
XM-42	0	0	240		849(2)	1106(4)
M-40	0	0.125	240		917(7)	1126(3)
XM-42	0	0.125	240		975(3)	1068(2)
XM-41	0	2.188	240			1911(4)
M-42E1	1.570	0.125	240		977(3)	
XM-42	1.570	0.125	240		992(3)	1160(3)
M-40	1.875	0.125	240		925(5)	1372(11)

TABLE VI (C). Impacting Mass-Velocity Combinations Required to Detonate High Order Sub-Missile Munitions 50% of the Time (U)

Mass (grains)	Median Values (mps)	$\overline{V}_{.5}$ (mps)	σ (mps)	Shielding[a] Aluminum	Spacing[b]
30HD	2430[c]	224[illegible]	549	No	No
30	2195[c]			No	No
[illegible]	1[illegible]5	1405	68	No	No
120	1222			No	No
240	1052	[illegible]00	194	No	No
30HD	2[illegible]14	2430	3[illegible]5	Yes	No
30	2350			Yes	No
[illegible]	202[illegible]	1929	302	Yes	No
120	1[illegible][d]	1379	[illegible]	Yes	No
240	1790[d]	10[illegible]5	[illegible]	Yes	No
30HD	2[illegible]20	36[illegible]	[illegible]92	Yes	Yes
30	24[illegible]			Yes	Yes
[illegible]0	2408	22[illegible]	346	Yes	Yes
120	1[illegible]0	[illegible]502	[illegible]74	Yes	Yes
240	1200	1074	1[illegible]0	Yes	Yes

a. Shielding was either a 0.063 inch sleeve, a 0.125 inch plate or a combination of both plate and sleeve.

b. Spacing varied between 1.570 inches to 2.000 inches

c. Estimated. No data available.

d. Poor data point. XM-41 data used in the analysis adversely affected the median value. Use $\overline{V}_{.5}$ data.

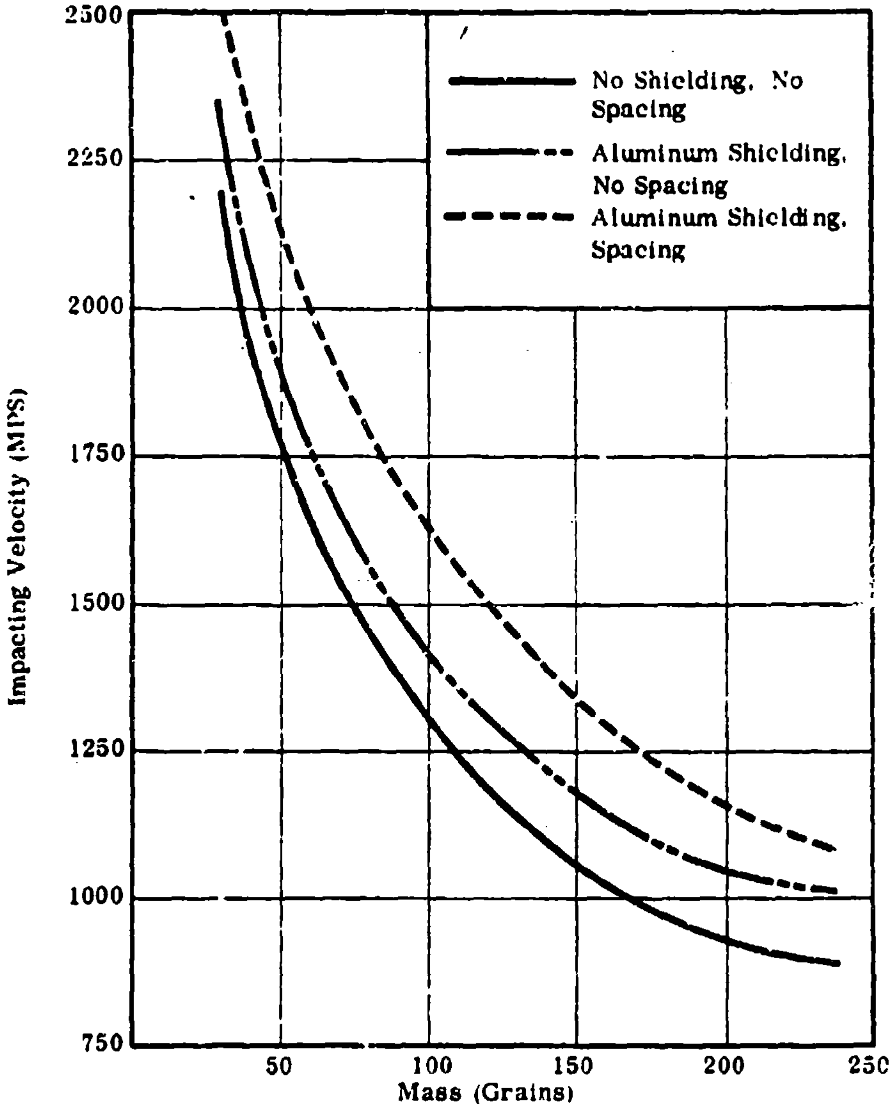

Figure 18 (C). Vulnerability of Sub-Missile Munitions to Fragment Impact (U)

that cast iron projectiles fracture when subjected to fragment impact at mass-velocity combinations well below those required to initiate an explosive reaction. The shock attenuation properties of cast iron probably provide some degree of protection against shock-initiated explosive reactions.

C. HE Filler Characteristics

Comp. B-filled artillery projectiles are more vulnerable to fragment impact than comparable rounds filled with TNT.

There does not appear to be any difference in the minimum impacting mass-velocity combinations required to initiate High Order and Low Order reactions for Comp. B-filled projectiles.

It is possible to explosively initiate a Comp. B-filled projectile, via fragment impact, at velocities below that required for perforation of the projectile wall. However, the mass-velocity combinations required to perforate the wall of TNT-filled projectiles was always exceeded, in this series of tests, before any explosive reactions were initiated. A residual mass-velocity criterion appears to be the only method available in making reasonable estimates on the vulnerability of the HE munitions tested utilizing a filler other than Comp. B.

The Sub-Missile munitions tested are equally vulnerable to fragment impact. It is reasonable to assume that other munitions in this class will respond similarly.

Because data were available on the vulnerability of bare Comp. B to fragment impact, it was possible to generate protection coefficients for Comp. B-filled munitions. These coefficients can be used in making reliable estimates on the vulnerability of Comp. B-filled munitions.

The results of this series of tests should prove useful to analysts in assessing the vulnerability of a wide range of HE ammunition to fragment impact. They should also be of value to those engaged in the design of new munitions. Attention has been focused on those parameters which influence the vulnerability of HE munitions. It appears likely that the vulnerability of conventional HE munitions can be significantly reduced.

(UNCL) VIII. RECOMMENDATIONS FOR FUTURE WORK

To provide those engaged in assessing and predicting the vulnerability of HE munitions to fragment or other type projectile impact with the information they require, the following recommendations are made.

A. Using instrumentation, establish an "absolute standard" for determining the response characteristics for High Order and Low Order reactions. This would provide test personnel in the field with a method for making quantitative assessments for all explosive reactions and assist the analyst in the application of the results.

B. Conduct firings against TNT-filled U.S. artillery projectiles. TNT is one of the least sensitive of the more common HE fillers while Comp. B. is one of the most sensitive.

C. Conduct additional firings against Comp. B and TNT-filled munitions and determine their vulnerability as a function of impact angle.

D. Determine the vulnerability of bare TNT to steel fragment impact. It may be that a relationship exists between the vulnerability of bare TNT and TNT-filled munitions. If a relationship does exist, it could provide the means for developing a predictive technique similar to that now available to analysts assessing the vulnerability of Comp. B-filled artillery munitions.

E. Through live firings, quantitatively assess the desensitizing effect, if any, of the more common and experimental materials that could be used as either a coating on the interior surface of the projectile or as an additive to the HE filler.

It is recognized that these additional investigations will not satisfy the requirements of all researchers. However, they should provide the vulnerability analyst with a data bank from which valid predictions can be made on the vulnerability of a wide variety of HE munitions to steel fragment impact.

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(CONFIDENTIAL) APPENDIX A

Steel Fragments Versus
U.S. Artillery Projectiles (U)

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A-1 (C). [illegible] –
[illegible]

[illegible] Mass (grains)	Impact Velocity (mps)	Result: Partial Penetration	Perforation
[illegible]	1[illegible]	X	
	1[illegible]		X
120	128[illegible]	X	
	1347	X	
	137[illegible]	X	
	136[illegible]		X
240	761	X	
	823	X	
	1047	X	
	1064	X	
	1082	X	
	1160		X
	1252		X
	1399		X

[illegible]: All fragments were aimed to impact at a point where the projectile wall measured 0.485 ± 0.013 inches and at an obliquity angle of zero degrees.

[illegible] A-II (c). [illegible] –
Fragments Versus [illegible] Projectile
(Empty and Wax Filled)

Fragment Mass (grains)	Impact Velocity (mp[illegible])	Projectile Filler	Wall Thickness (inches)	Results: Partial Penetration	Results: Perforation
30	1407	Empty	0.403± .012	X	
	1559	"	"	X	
	1721	"	"	X	
	1769	"	"	X	
	1885	"	"	X	
	1899	"	"	X	
	1923	"	"	X	
	1943	"	"		X
	2098	"	"		X
60	1389	Empty	0.403± .012	X	
	1407	"	"	X	
	1492	"	"	X	
	1533	"	"		X
	1525	Wax	"	X	
	1579	"	"	X	
	1670	"	"		X
	1780	"	"		X
	1986	"	"		X
120	979	Empty	0.403± .012	X	
	994	"	"	X	
	1124	"	"	X	
	1134	"	"		X
	1172	"	"		X
	1216	"	"		X
	1252	"	"		X
	1255	"	"		X
240	691	Empty	0.403± .012	X	
	788	"	"	X	
	802	"	"	X	
	941	"	"	X	
	955	"	"		X
	997	"	"		X
	1006	"	"		X
	1022	Wax	"	X	
	1096	"	"		X
	1272	"	"		X

A-II [illegible] (Continued)
[illegible] RESULTS –
Fragments versus [illegible] mm [illegible] Projectile
(Empty and [illegible] Filled) [illegible]

[illegible] Mass (grains)	Impact Velocity	Projectile Filler	Wall Thickness (inches)	Results: Partial Penetration	Results: Perforation
30	[illegible]	Empty	[illegible] ± .012	X	
	2041	"	"	X	
	2083	"	"	X	
[illegible]	[illegible]	Empty	0.[illegible] ± .012	X	
	[illegible]	"	"	X	
	[illegible]	"	"	X	
	[illegible]	"	"		X
	[illegible]	"	"		X
	[illegible]	"	"		X
[illegible]	1176	Empty	[illegible] ± .012	X	
	[illegible]	"	"	X	
	[illegible]	"	"	X	
	[illegible]	"	"	X	
	[illegible]	"	"		X
240	[illegible]	Empty	[illegible] ± .012	X	
	[illegible]	"	"	X	
	1062	"	"		X

NOTE: All fragments were aimed to impact at a point where the projectile wall measured 0.403 or 0.50 ± 0.030 inches and at an obliquity angle of zero degrees.

TABLE A-III (C). CLASSIFICATION OF RESULTS –
Fragments Versus 155mm HE Projectile (Empty) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results: Partial Penetration	Results: Perforation
60	1970	X	
	1975	X	
	2012	X	
	2059		X
120	1476	X	
	1519	X	
	1531		X
	1551		X
	1612	X	
	1617	X	
	1629		X
	1676		X
	1708		X
	1815		X
240	1282	X	
	1378		X
	1386		X

NOTE: All fragments were aimed to impact at a point where the projectile wall measured 0.56 ± 0.030 inches and at an obliquity angle of zero degrees.

TABLE A-IV (C). CLASSIFICATION OF RESULTS — Fragments Versus 175mm HE Projectile (Empty) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results: Partial Penetration	Results: Perforation
[illegible]	[illegible]	X	
	[illegible]		X
	2020		X
	[illegible]		X
120	1317	X	
	1327	X	
	1341	X	
	1360	X	
	1429	X	
	1459		X
	1472		X
	1476		X
	1479		X
	1505		X
	1622		X
	1627		X
240	1035	X	
	1096		X
	1160		X
	1190		X

NOTE: All fragments were aimed to impact at a point where the projectile wall measured 0.525 ± 0.030 inches and at an obliquity angle of zero degrees.

TABLE A-V (C). CLASSIFICATION OF RESULTS — Fragments Versus 90mm HE Projectile (Composition B) (U)

Fragment Mass (grains)	Impact Velocities (mps)				
	High Order	Low Order	Burn	No Reaction	
60	2187	2060 2088 2104 2117 2126 2151 2154 2328	2111*	1847 1893 1902 1952 2020 2033 2059 2068 2066	2074 2085 2101 2131 2131 2146 2146 2162 2171
120	1525 1568 1571 1571 1580	— 1552 1553 1554 1568 1586		1463 1529 1554 1585	
240	1319 1342 1362 1386	1228 1228 1334	1204* 1319*	1179 1191 1202 1205 1223	1239 1243 1253 1254 1260*

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of zero degrees.

TABLE A-VI (C). CLASSIFICATION OF RESULTS – Fragments Versus 105mm HE Projectile (Composition [illegible]) (U)

Fragment Mass (grains)	Impact Velocities (mps)			
	High Order	Low Order	Burn	No Reaction
30	[illegible] 2350 [illegible] [illegible] [illegible] 2720 [illegible] [illegible] 2894		[illegible] 2711*	2171* 2190 2287 2313 2355 2357 2387 2409 2454 2459 2482* 2513 2585* 2609 2621 2623 2635 2638 2675 2687* 2687 2725* 2726* 2745 2867*
[illegible]	1720 1783 1835 1894 1876 1876 1976	1347 1571 1879		1699 1717 1739 1754* 1754 1775 1785 1863 1886
120	1444 1446 1449 1477 1494	1456	1496* 1584*	1175 1211* 1271* 1412* 1417* 1417 1420* 1449* 1467* 1495* 1531*
240	1209 1225 1232 1251	1202	1279*	925* 1007* 1022 1089* 1092* 1131* 1131* 1207* 1207* 1210* 1236* 1237*

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of zero degrees.

TABLE A-VII (C). CLASSIFICATION OF RESULTS – Fragments Versus 105mm HE Projectile (Composition B) (U)

Fragment Mass (grains)	Impact Velocities (mps)				
	High Order	Low Order	Burn	No Reaction	
120	1629			1525	1660*
	1668			1544*	1670
	1752			1548*	1670
	1805			1553	1679
	1840			1564	1691
				1585	1725*
				1587	1735*
				1605	173[illegible]
				1614*	1769
				1658	
240	1690		1620*	1236	1579*
	1692			1565*	1589*
				1568*	1591*
				1571*	1639*
				1572	1646*
				1575*	1717*

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of forty-five degrees.

TABLE **A-VIII (C).** CLASSIFICATION OF RESULTS – Fragments Versus 105mm HE Projectile (Composition B) (U)

Fragment Mass (grains)	Impact Velocities (mps)			
	High Order	Low Order	Burn	No Reaction
120	1524 1543 1624 1647 1675 1718 1761 1797 1799 1815			1369 1397 1483 1486 1518 1521 1525 1536 1554 1559 1636
240	1319 1332 1337 1358 1372 1375 1378 1410 1462			958 1219 971 1242 974 1266 1019 1281 1046 1284 1072 1292 1085 1372 1089* 1421

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of zero degrees.

TABLE A-IX (C). CLASSIFICATION OF RESULTS – Fragments Versus 175mm HE Projectile (Composition B) (U)

Fragment Mass (grains)	Impact Velocities (mps)				
	High Order	Low Order	Burn	No Reaction	
120	1747	1836		1446	1874
	1757	1868		1510	18[illegible]*
	1876	1879		1607	19[illegible]
	1955	1884		1692	1923
		1952		1723	1931
		2002		1749	1940
				*17[illegible]	[illegible]
				1786	19[illegible]
				1817	19[illegible]
240	1288	1326		1066	1272
	1405	1413		1162	128[illegible]
	1432			1167	130[illegible]*
	1455			1196	1334
	1464			11[illegible]	1339
	1566			1235	1344
				1237	1365
				1242	1369
				1243	1434
				1250	1440
				1258	1463
				1260	

* Indicates that the projectile wall was perforated. All fragments were aimed to impact at an obliquity angle of zero degrees.

(CONFIDENTIAL) APPENDIX B

Steel Fragments Versus Soviet
Artillery and Rocket Projectiles (U)

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TABLE B-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Soviet [illegible]mm HE Projectile (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results
[illegible]	[illegible]3	Projectile wall perforated.* Slight burning.
[illegible]	1[illegible]	[illegible] hit. Fragment impacted on rotating band. No perforation.
12[illegible]	1[illegible]	Projectile wall perforated. No burning or explosive reaction observed.
120	1[illegible]	Projectile wall perforated. Slight burning.
120	1[illegible]3[illegible]	Projectile wall perforated. Slight burning.
240	1280	Projectile wall perforated. No burning or explosive reaction observed.
240	1521	Low order reaction.
240	1524	Projectile wall perforated. No burning or explosive reaction observed.
240	1630	Low order reaction.
240	1[illegible]32	Low order reaction.

*The aim point was mid-way between the bourrelet and the rotating bands. The obliquity angle was zero degrees. The wall thickness at this point is 0.460 inches. The HE filler is RDX 73%; aluminum 23%; wax 4%.

TABLE B-II (C). CLASSIFICATION OF RESULTS
Fragments and Bullets Versus Soviet
122mm HE Artillery Projectile (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results
60	2330	Fragment hit two inches low of intended point of impact.* No perforation or explosive reaction.
60	2345	Fragment hit one inch low of intended point of impact. No perforation or explosive reaction.
60	2502	Projectile wall perforated. Slight burning.
60	2540	Fragment hit one half inch to the right of the intended point of impact. No perforation or explosive reaction.
60	2536	Projectile wall perforated. Slight burning.
60	2574	Fragment hit one half inch to the right of the intended point of impact. No perforation or explosive reaction.*
60	2605	Low Order Reaction.
60	2610	Low Order Reaction.
60	2641	Fragment hit one half inch low and one half inch to the left of the intended point of impact. Projectile wall perforated. Slight burning.
60	2669	Projectile wall perforated. Slight burning.
120	1679	No perforation or explosive reaction.
120	1752	No perforation or explosive reaction.
120	1939	Fragment hit one inch high of the intended point of impact. Projectile wall perforated. Slight burning.

*The aim point was one inch below the bourrelet. The obliquity angle was zero degrees. The wall thickness at this point is 0.620 inches.

TABLE B-II (C). CLASSIFICATION OF RESULTS
Fragments and Bullets Versus Soviet
[illegible] (Continued) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results
[illegible]	[illegible]	Projectile wall perforated. Explosive burned for 45 minutes.
120	[illegible]	Fragment hit one inch low of the intended impact point. Projectile wall perforated. Slight burning.
240	1300	No perforation or explosive reaction
240	14[illegible]1	Fragment hit one inch high of the intended point of impact. Projectile wall perforated. Slight burning.
240	[illegible]	Fragment hit one inch low of the intended point of impact. Projectile wall perforated. Slight burning.
240	1628	Low order reaction.
240	1688	Low order reaction.
240	1760	Low order reaction.
240	1804	Low order reaction.
[illegible]	[illegible]	A .50 cal. ball bullet was used in this test resulting in a low order reaction.

TABLE B-III (C). CLASSIFICATION OF RESULTS -- Fragments Versus Soviet 140mm HE Rocket Projectiles (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Wall Thickness (inches)	Obliquity Angle (degrees)	Results
240	1830*	0.375	0	Low Order.
240	1678*	0.375	0	Wall perforated. No explosive reaction.
240	1678*	0.375	0	Fragment impacted 1-inch to the right of desired impact point. Wall perforated. No explosive reaction.
240	1531	0.375	0	Wall perforated. Slight burning.
240	1824	0.375	0	High Order.
240	1835	0.375	45	Wall perforated. Explosive burned for 50-minutes.
240	1844	0.60	0	High Order.
240	1794	0.60	0	Wall perforated. No explosive reaction.
240	1779	0.60	0	Wall perforated. No explosive reaction.
480	1120	0.375	0	Fragment impacted 1-inch to the right of desired impact point. Wall perforated. No explosive reaction.
480	1115	0.375	0	Wall perforated. No explosive reaction.
480	1085	0.375	0	Wall perforated. No explosive reaction.

* Estimated Velocities

TABLE B-III (C). CLASSIFICATION OF RESULTS — Fragments Versus Soviet [illegible]mm HE Rocket Projectiles ([illegible]) **(continued) (U)**

Fragment Mass (grains)	Impact Velocity (fps)	Wall Thickness (inches)	Obliquity Angle (degrees)	Results
[illegible]	1131	[illegible]	[illegible]	Fragment impacted 1-inch to the right of desired impact point. No explosive reaction.
[illegible]	11[illegible]2	0.[illegible]	[illegible]	Wall perforated. No explosive reaction.
[illegible]	1[illegible]	[illegible]	[illegible]	No wall perforation. No explosive reaction.

TABLE B-IV (C). CLASSIFICATION OF RESULTS
Fragments and Bullets Versus Soviet
152mm HE Artillery Projectile [illegible] (U)

Fragment Mass (grains)	Impact Velocity (mps)	Results
[illegible]	[illegible]	Fragment failed to perforate projectile wall.* No burning or explosive reaction.
120	2281	Fragment failed to perforate projectile wall. No burning or explosive reaction
120	2316	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2316	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2345	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2352	Fragment failed to perforate projectile wall. No burning or explosive reaction.
120	2377	Fragment failed to perforate projectile wall. No burning or explosive reaction.
240	1795	Fragment failed to perforate projectile wall. No burning or explosive reaction.
240	1944	Fragment failed to perforate projectile wall. No burning or explosive reaction.
780	869	A .50 cal. ball bullet was impacted at an obliquity angle of zero degrees resulting in a low order reaction.
780	[illegible]	A .50 cal. ball bullet was impacted at an obliquity angle of 45 degrees resulting in a low order reaction.

*The aim point was one inch below the bourrelet. The wall thickness at this point is 0.790 in. All fragments were aimed to impact at an obliquity angle of zero degrees.

(CONFIDENTIAL) APPENDIX C

Steel Fragments Versus U.S. 81mm
and Soviet/CHICOM Mortar Projectiles (U)

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TABLE C-I (C). CLASSIFICATION OF RESULTS – Fragments Versus U.S. 81mm Mortar Projectiles (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Obliquity Angle (degrees)	Masking	Fuze	Results
60	1800	0	3/4" **Pine**	No	Perforation. Small amount of HE burned. Impacted 2" below gas check bands.
120	1647	0	"	No	Small amount of HE burned. Part of the plastic nose cap broken. Impacted 2" below gas check bands.
120	1647	0	None	No	Some HE burned. Nose cap knocked off. Unburned HE scattered around. Impact below gas check bands.
120	1891	0	None	No	Mild low order reaction. Round broke up into a few large pieces. Impact below gas check bands.
120	2135	0	3/4" **Pine**	No	A flash observed as the HE burned. No breakup of the projectile. Nose plug knocked off. Impact below gas check bands.
120	1891	0	"	No	Some of the HE burned. Nose plug knocked off. Impact below gas check bands.
120	1890	0	"	No	Same as previous round.
120	2130	0	"	No	Same as previous round.
120	2135	0	"	No	Impacted on gas check bands. Some HE burned.

TABLE C-I (C). (Continued)

CLASSIFICATION OF RESULTS –
Fragments Versus U.S. 81mm Mortar
Projectiles (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Obliquity Angle (degrees)	Masking	Fuze	Results
120	2135	0	3/4" Pine	Yes	Fuze armed with safety devices attached. Mild low order. Projectile casing opened completely. Impacted one inch below gas check bands.
120	2135	45	"	No	Perforation, no burning. Impact on gas check bands.
120	2135	45	"	No	Same as previous round.
240	1830	0	"	No	Mild low order, projectile fractured into three pieces. Sustaining wood fire started in packing box below the round. Impact on gas check bands.
240	1594	0	"	No	Some HE burned. Impact on gas check bands.
240	1427	0	"	No	Some HE burned. Unburned HE scattered about. Impact on gas check bands.
240	1830	0	"	No	Three rounds placed in a six-round Soviet type container. A weighted wooden box placed above. Fragment impacted on gas check band. Low order reaction of the impacted round. Other rounds slightly damaged.

TABLE C-I (C) (Continued)

CLASSIFICATION OF RESULTS –
Fragments Versus U.S. 81mm Mortar
Projectiles (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Obliquity Angle (degrees)	Masking	Fuze	Results
120	2135	0	None	No	Impacted one inch below gas check rings. Mild low order reaction. Projectile broke into three sections.

TABLE C-II(C). CLASSIFICATION OF RESULTS – Fragments Versus Soviet/CHICOM 82mm HE Mortar Projectiles (TNT) (U)

Fragment Mass (grains)	Impact Velocity (mps)	Obliquity Angle (degrees)	Fuze (Unarmed)	Results
60	946	0	Yes	Fragment impacted at 0° on the unarmed fuze. The plastic fuze was shattered. No explosive or burning reaction observed.
120	1891	0	No	Fragment impacted on gas check rings. The cast iron projectile fractured into ten pieces. No explosive reaction or burning observed.
240	945	20	Yes	Fragment impacted one inch below the fuze, 20° off the nose. Top section of the projectile fractured into several pieces. Fuzes, undamaged, thrown about ten feet. No explosive or burning reaction observed.
240	1586	0	No	Projectile, impacted on gas check rings, fractured into twelve pieces. No explosive or burning reaction observed.
240	1830	0	Yes	Projectile, impacted one inch below gas check rings, fractured into 26 pieces. No explosive or burning reaction observed.

(CONFIDENTIAL) APPENDIX D

Steel Fragments Versus
U.S. Sub-Missile Munitions (U)

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TABLE D-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC[a]	LO[b]	HO[c]
M-32	30HD[d]	0	0	2583	1793 2072 2540 2626 2628 2674	2562 2671 2671 2768 2802
M-32	30HD	0	0.125[e]	2354	1732 2316 2325 2471 2478 2559 2603 2668	2540 2573 2643 2650 2727
M-32	30HD	1.875	0.125		1860 .63 2682	

a. RC = Ruptured Case
b. LO = Low Order Reaction
c. HO = High Order Reaction
d. 30HD = 30 Grain high density steel, remainder of fragments are mild steel
e. 0.125 = An aluminum plate 0.125 inches thick
0.063 = An aluminum plate 0.125 inches thick
0.188 = Combination of 0.063 sleeve and 0.125 plate
2.188 = Combination of 0.063 sleeve, 0.125 plate and w.0 inches polyurethane

TABLE D-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC[a]	IO[b]	HS[c]
M-32	30HD	2.000	0.125	2610 2659	1845 2191 2340 2571 2586 2600 2614 2628 2633 2639 2659 2711 2731 2746 2746 2758	2448 2679 2753
M-40	30HD	0	0	1688	2239 2327	2429 2476 2507
M-40	30HD	0.	0.125	2697	1797 2326 2372 2534 2543 2636 2662	2591 2605 2628 2639 2674

TABLE D-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC[a]	LO[b]	HO[c]
M-40	30HD	1.875	0.125	1539 1997 2080 2561	2233 2372 2537 2572 2577 2630 2645 2647 2751 2842	
M-40	60	0	0			1964 2011 2021 2044
M-40	60	0	0.125		1854 1873	1948 2032 2034 2279
M-40	60	1.750	0.125		1846 1873	2225 2266
M-40	60	1.875	0.125		2133 2202 2205 2237	2340 2340

TABLE D-I(C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				HC[a]	LO[b]	HC[c]
M-40	120	0	0			1106 1222 1258
M-40	120	0	0.125		1408 1487 1492 1509 1704 1795 1564	1328 1526 1540 1651 1702 1869 1874 1679 [illegible]
M-40	120	1.750	0.125		980	[illegible]
M-40	120	1.875	0.125		1526 1654 1660 1637	1478 1524 1517 1646 1660 1859
M-40	240	0	0		839 888 980 1010 1023	1102 1107 1104 1121 1553

TABLE D-I (C). CLASSIFICATION [illegible]
Fragments Versus Sub-Missile [illegible] (Continued)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				[illegible][a]	[illegible][b]	[illegible][c]
M-40	240	0	0.125		80 [illegible] 848 914 917 985 [illegible]	1107 1126 1790
M-40	240	1.875	0.125		811 856 925 1051 1058	754 1154 1191 1201 1217 1372 1374 [illegible] 1500 1767 1794
M-42E1	30	0	0.125			2345 2347 2353 2560
M-42E1	30	1.570	0.125			2455 2469 2476

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TABLE D-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				NC[a]	LC[b]	HO[c]
M-42E1	60	0	0.125			1874 1882 1886
M-42E1	60	1.570	0.125		2051 2062	1368
M-42E1	120	0	0			1103 1116 1181 1404 1424 1431
M-42E1	120	1.570	0.125			1593 1630 1643
M-42E1	240	0	0			768 777 1029 1033 1052 1245
M-42E1	240	1.570	0.125		976 977 1097	

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TABLE D-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC[a]	LC[b]	HC[c]
XM-41	30HD	0	0.125			2354 2556 2614 2630
XM-41	30HD	0	2.188			2630
XM-41	60	0	0.125		1878 1974	1969 2027
XM-41	120	0	2.188		1817	1954 1955 1974 [illegible]
XM-41	240	0	2.188			1829 1854 1938 1948
XM-42	30HD	0	0	1553	1576 1739 2243 2252 2294	1864 [illegible] 2249 2340 2354 2376 2378 2372 2413 [illegible]

TABLE D-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				R[a]	LO[b]	HO[c]
XM-42	30HD	0	0.125		[illegible]	[illegible] 2372 [illegible] [illegible] [illegible] 2516 2530
XM-42	30HD	0	[illegible]			2674
XM-42	60	0	0		1326 1365 [illegible] [illegible]	[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] 1670 [illegible]
XM-42	60	0	0.125		[illegible] 1920	[illegible] 1923
XM-42	60	0	0.18[illegible]		[illegible] [illegible] 2091 [illegible] [illegible]	[illegible] 2249 2336 2347

TABLE D-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC[a]	LO[b]	HO[c]
XM-42	60	1.570	0.188	2455 2473	2265 2292	2476 2494 249[illegible] 2501 2506
XM-42	120	0	0.063		1191 1202 1204 1204	1279 1287 1289 1291 1368 1433 1503 1608
XM-42	120	0	0.188		1487 1659 1704 1742	1828 1909 1920
XM-42	120	1.570	0.188		1754 1809 1836 1839	1873 1890 1926 1935
XM-42	240	0	0		826 872	971 992 1020 1088

TABLE D-I (C). CLASSIFICATION OF RESULTS
Fragments Versus Sub-Missile Munitions (Continued) (U)

Target Type	Fragment Weight (grains)	Spacing (inches)	Aluminum Shielding (inches)	Impact Velocities (mps)		
				RC[a]	LO[b]	HO[c]
XM-42	240	0	0.125		972 975 1054	1035 1037
XM-42	240	1.570	0.125		963 992 1046	1155 1160 1166

TABLE D-II (C). CLASSIFICATON OF RESULTS
30 Grain HD Fragments Versus Groups of XM-41
Sub-Missiles in Aluminum Containers (U)

Number of Rounds in Container	Container Size (inches)			Configuration	Impact Velocity (mps)	Results
	Length	Diameter	Wall Thickness			
6	5.70	3.44	0.125	Two layers of three each	2550	All rounds functioned high order
6	5.70	3.44	0.125	Two layers of three each	2488	All rounds functioned high order
14	5.70	8.75	0.125	Two layers of seven each	2040	All units functioned high order
14	5.70	8.75	0.125	Two layers of seven each	2577	All units functioned high order
14	5.70	8.75	0.125	Two layers of seven each	2583	All units functioned high order
14	5.70	8.75	0.125	Two layers of seven each	2608	All units functioned high order
14	5.70	8.75	0.125	Two layers of seven each	2079	All units functioned high order
14	5.70	8.75	0.125	Two layers of seven each	2691	All units functioned high order

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(CONFIDENTIAL) APPENDIX E

Engineering Drawings of U.S. Artillery Projectiles,
Soviet Artillery and Rocket Projectiles,
U.S. and Soviet/CHICOM Mortar Projectiles (U)

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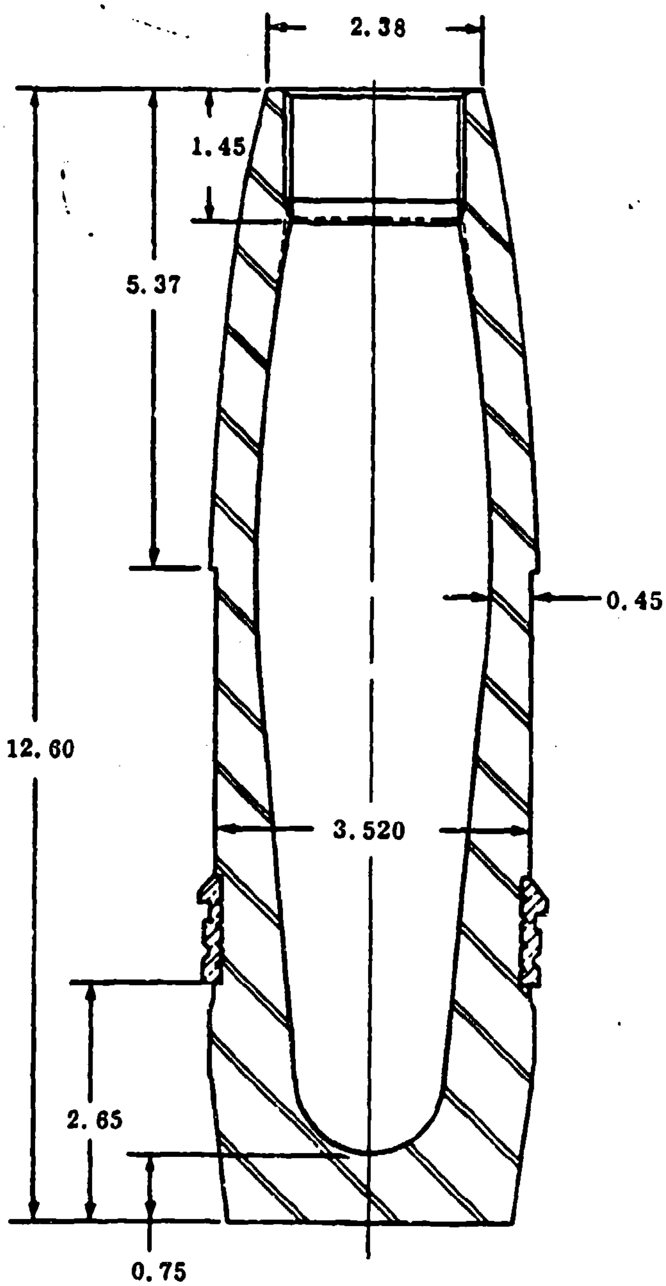

Figure E-1. Shell for U.S. 90mm Artillery Projectile

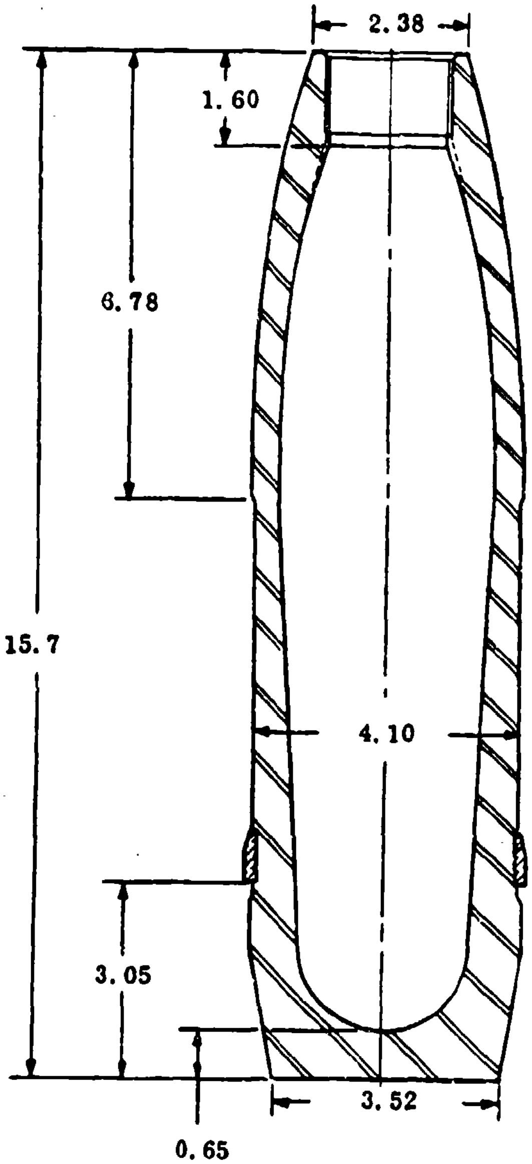

Figure E-2. Shell for U.S. 105mm Artillery Projectile

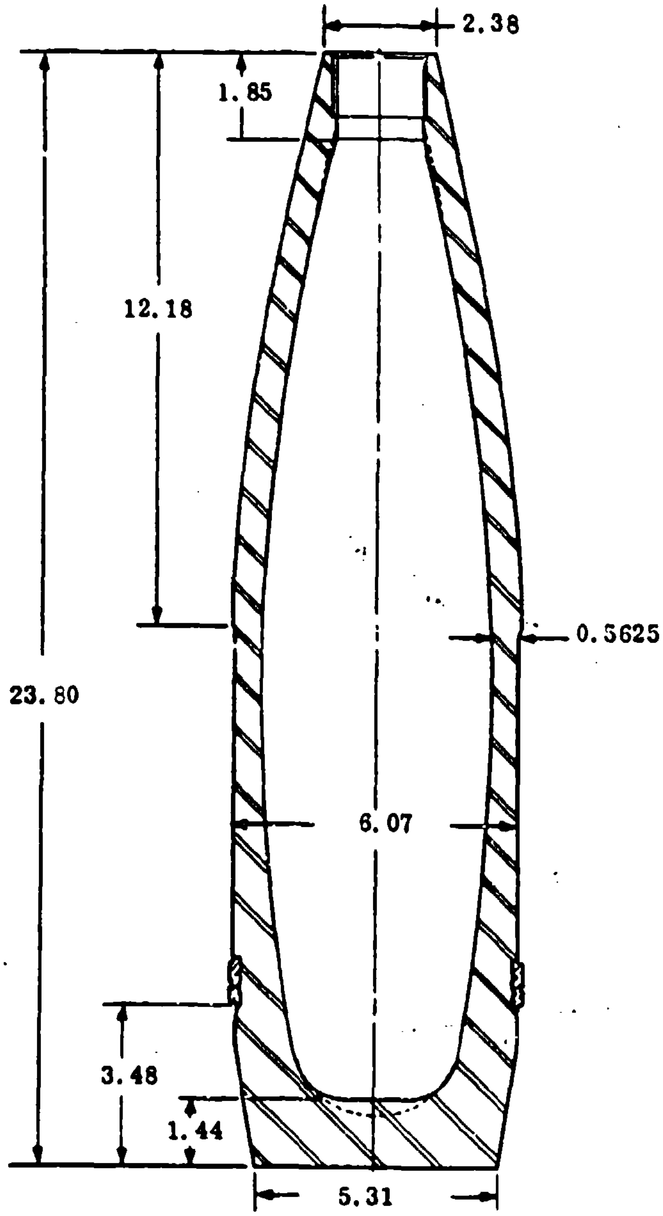

Figure E-3. Shell for U.S. 155mm Artillery Projectile

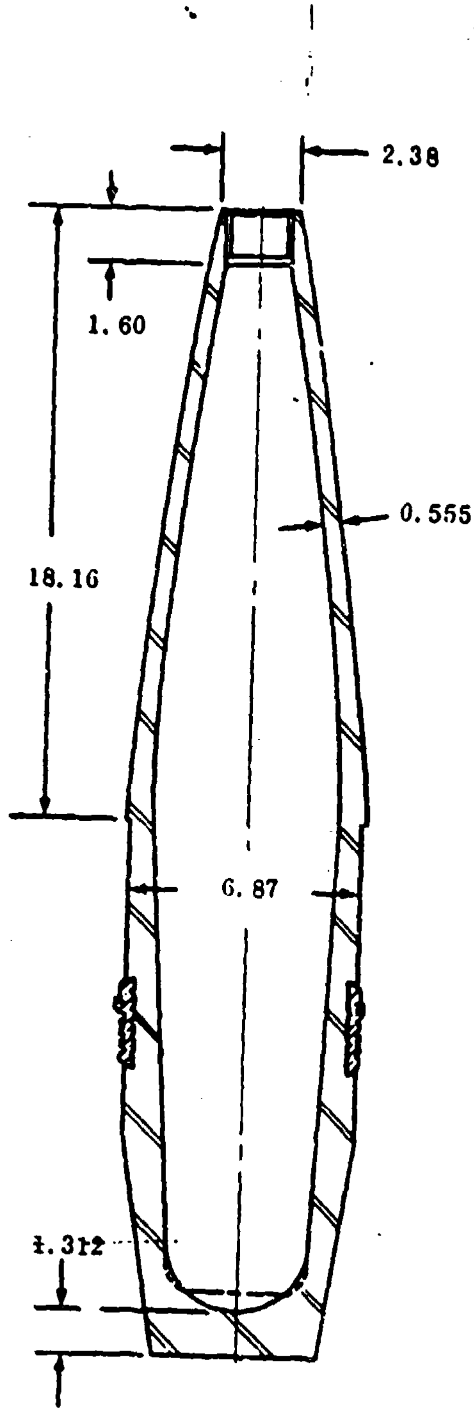

Figure E-4. Shell for U.S. 175mm Artillery Projectile

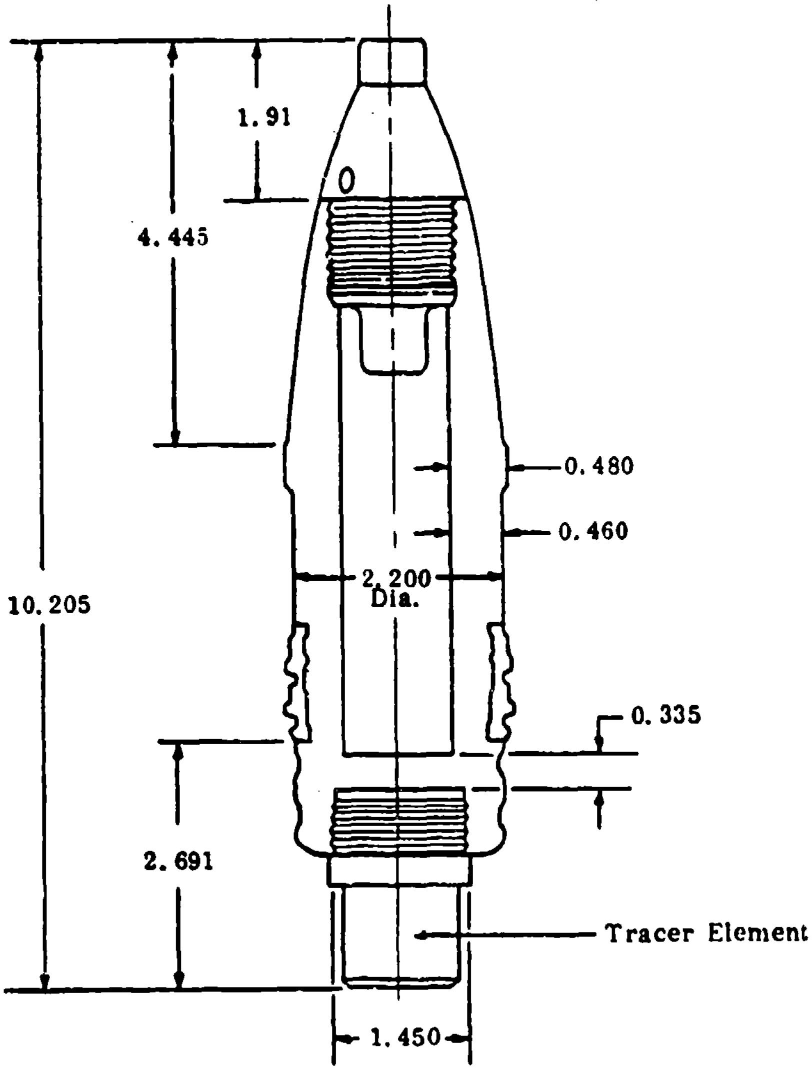

Figure E-5 (C). Shell for Soviet 57mm Artillery Projectile (U)

[redacted]

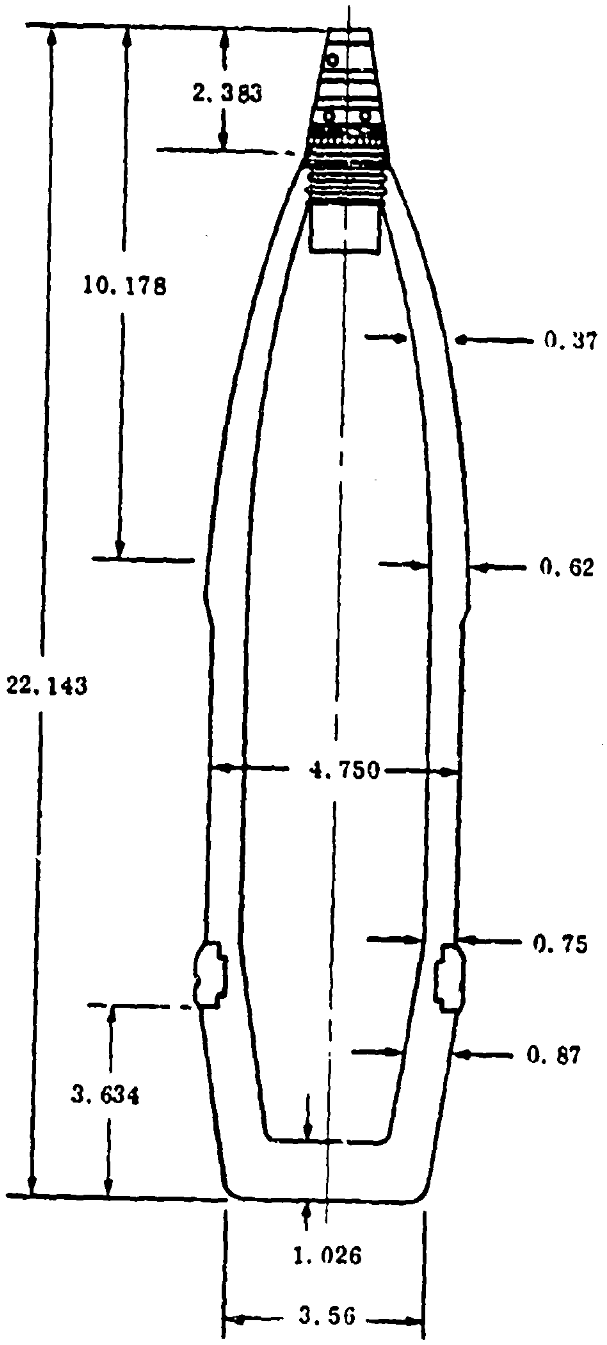

Figure E-6 (C). Shell for Soviet 122mm Artillery Projectile (U)

[redacted]

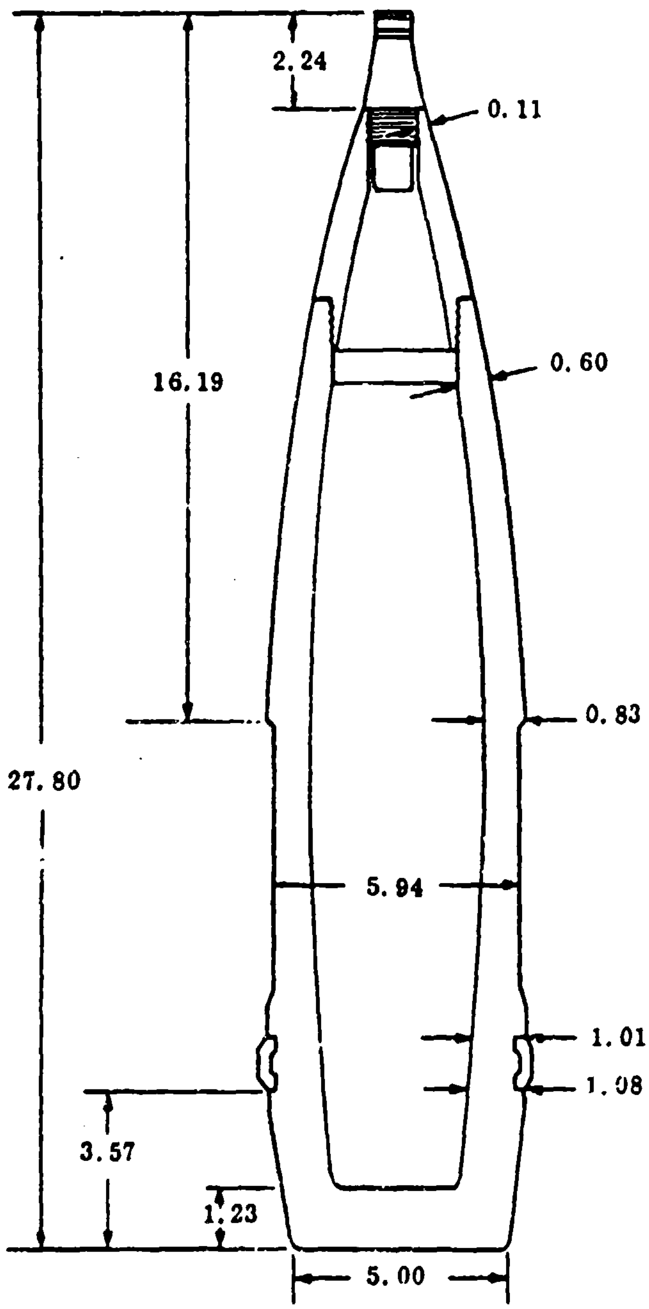

Figure E-7 (C). Shell for Soviet 152mm Artillery Projectile (U)

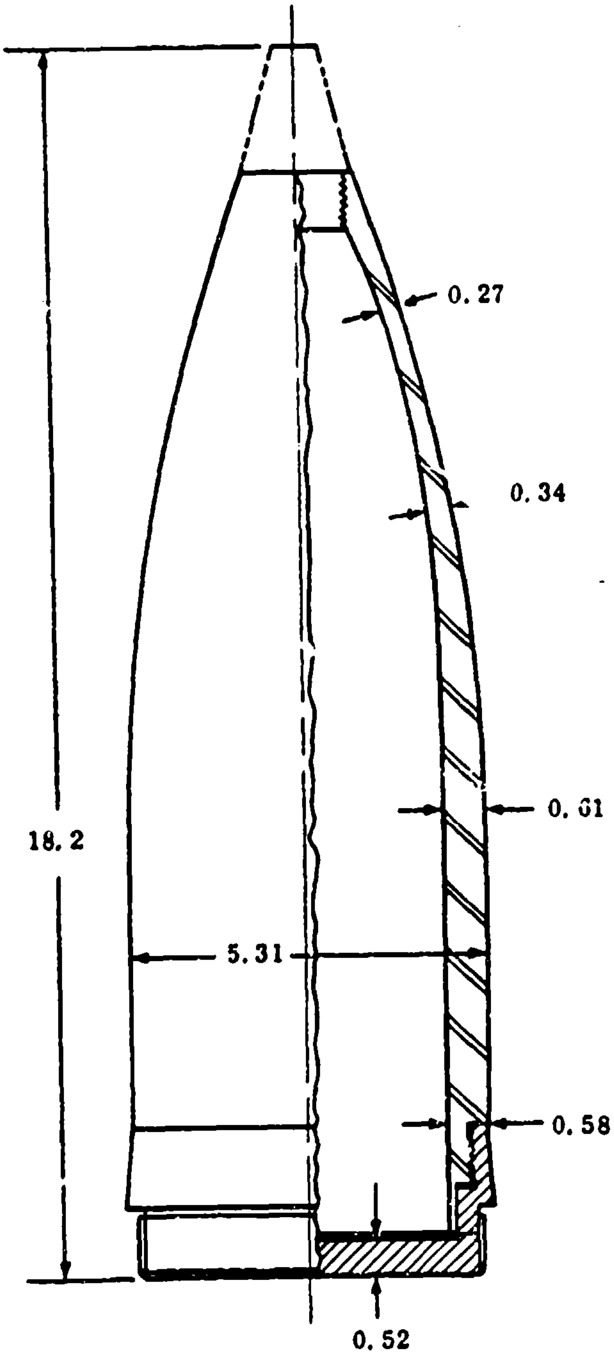

Figure E-8 (C). Shell for Soviet 140mm Rocket Projectile (U)

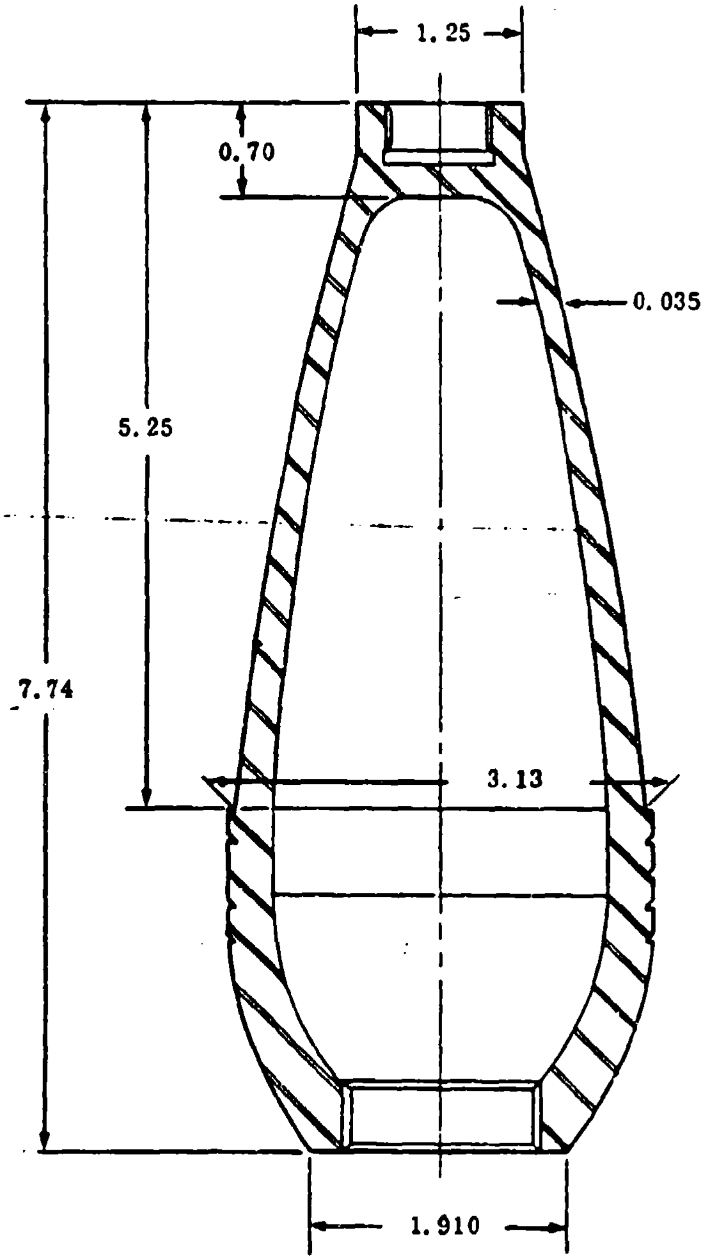

Figure E-9. (U) Shell for U.S. 81mm Mortar Projectile

[redacted]

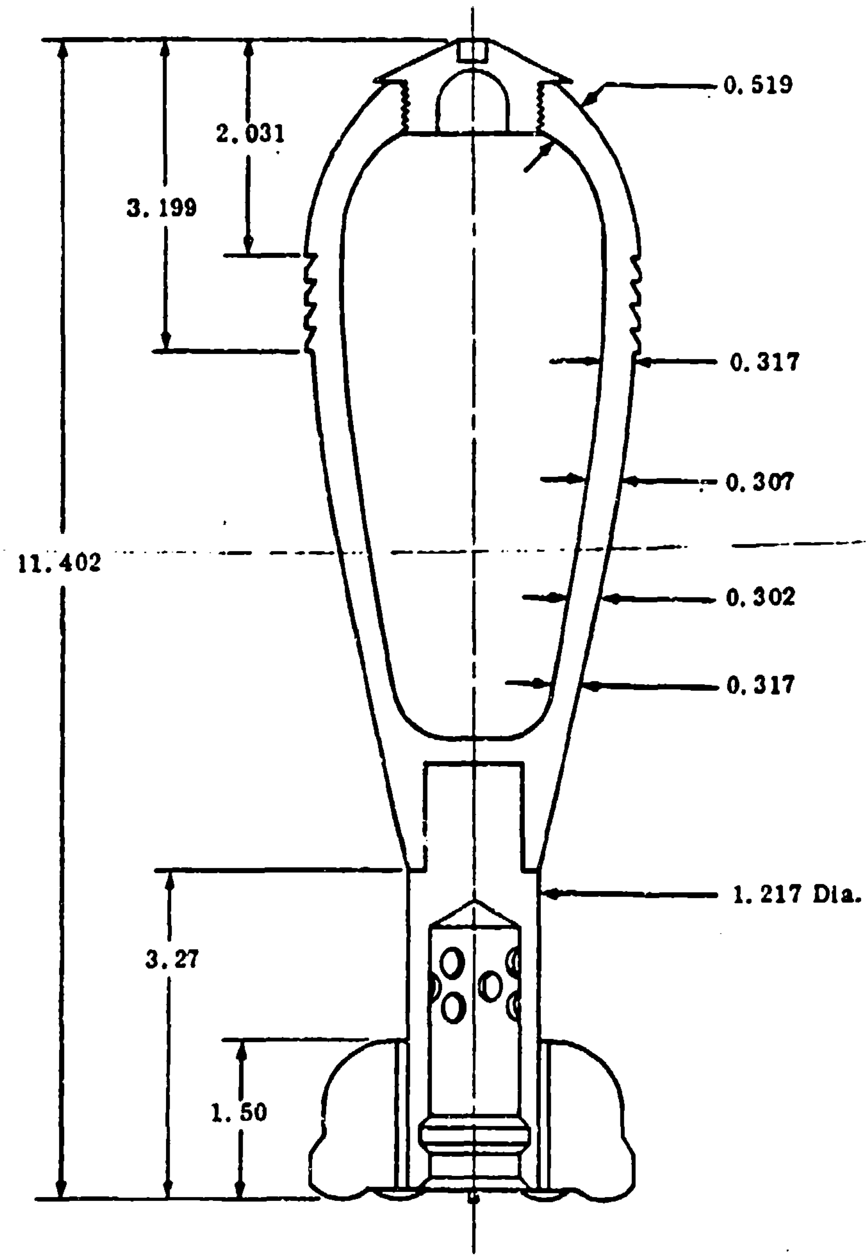

Figure E-10 (C). Shell for CHICOM 82mm Mortar Projectile (U)

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13. ABSTRACT

Efforts to derive a satisfactory measure of the vulnerability of High Explosive munitions to steel fragment impact have been hampered by a lack of experimental data. In an attempt to remedy this deficiency, a number of tests have been carried out. (U)

This report presents the results of tests of firings of steel fragments against U.S. 90mm, 105mm, and 175mm HE (Comp. B) artillery projectiles, Soviet 57mm HE (RDX/aluminum/wax) artillery projectiles, Soviet 122mm and 152mm HE (TNT) artillery projectiles, Soviet 140mm HE (TNT) rocket projectiles, U.S. 81mm and Soviet/CHICOM 82mm mortars (TNT), and a variety of U.S. Sub-Missile munitions. (U)

These firing data were used to determine contributions of fragment striking mass and velocity required to initiate explosive reactions. (U)

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KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ammunition Vulnerability						
Steel Fragment Impact						
High Explosive Sensitivity						
High Order Reactions						
Low Order Reactions						

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